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Porous Dike Intake Evaluation

New England Electric System, Westborough, MA

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POROUS DIKE INTAKE EVALUATION

by

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16. ABSTRACT The report gives results of an evaluation of a porous dike intake. A small-scale test facility was constructed and continuously operated for 2 years under field conditions. Two stone dikes of gabion construction were tested: one consisted of 7.5 cm stones; and the other, 20 cm stones. Approach velocity was set at 3 cm/sec. Using a test flume, laboratory studies were also conducted on the avoidance response of fish to a porous dike intake. Flow through a porous dike, induced by a hydraulic head of about 61 cm, depended on the cross-sectional area (tidal height). Throughout the experiment, flow resistance changed, depending on the fouling. Increases in flow resistance resulted in lower flow rates at constant hydraulic head. Flow rates could be increased by backflushing the stone dike. Throughout the experiment, the porous dike showed a steady accumulation of silt and organic matter, but the flow rates tended not to decrease with time. Analysis of field and laboratory data showed that the number of zooplankton is reduced passing through a porous dike by a combination of physical filtration and cropping. No zooplankton avoidance was substantiated. Analysis also indicated that the number of passively drifting larval fish is reduced passing through a porous dike by filtration or cropping. No conclusive field evidence indicated actively swimming larval fish avoid passing through the dike.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Dikes	Stationary Sources	13M
Porosity	Porous Dikes	14G
Intake Systems	Larval Fish	21J
Avoidance Responses		05J
Fishes		06C, 08A
Zooplankton		
Larvae		

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ABSTRACT

The objectives of this research program were to evaluate the hydraulic performance, fouling rate and screening performance of a porous dike intake.

A small-scale porous dike was constructed and continuously operated over a two-year period under actual field conditions. Two stone dikes were tested; one made of 7.5 cm stones and the other made of 20 cm stones. Both dikes were of gabion construction. Approach velocity was set at 3 cm/sec. Additionally, laboratory studies were conducted on the avoidance response of fish to a porous dike intake. Laboratory tests were conducted in a test flume.

Results include the hydraulic characteristics of flow through a porous dike, the rate of material deposition within the stone dike and the screening performance.

Flow through a porous dike induced by a hydraulic head of approximately 61 cm was dependent upon the cross-sectional area (tidal height). Throughout the experiment, flow resistance changed depending upon the fouling. Increases in flow resistance resulted in low flow volumes, while hydraulic head remained constant. Flow volumes could be increased by backflushing of the stone dike. Throughout the experiment, the porous dike showed a steady accumulation of silt and organic matter, but flow tended to stabilize.

Analysis of field and laboratory data showed that the numbers of zooplankton are reduced passing through a porous dike by a combination of physical filtration and cropping. No zooplankton avoidance was substantiated. Analysis also indicated that the numbers of passively drifting larval fish are reduced passing through a porous dike by filtration or cropping. No conclusive field evidence was obtained to explain if actively swimming larval fish avoid passing through the dike; however, limited laboratory results suggest avoidance may occur. Results with juvenile and adult fish show that they avoid passing through a porous dike.

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Abbreviations and Symbols

ANOVA	-- Analysis of Variance
cfs	-- cubic feet per second
cm	-- centimeter
cps	-- centimeters per second
cm/sec.	-- centimeters per second
cms	-- cubic meters per second
ft.	-- feet
$ft.^3/sec.$	-- cubic feet per second
ft./sec.	-- feet per second
fps	-- feet per second
h	-- head
in	-- inches
k	-- flow coefficient
l	-- liter
m	-- meter
$m^3/sec.$	-- cubic meters per second
ml	-- milliliter
mm	-- millimeter
Q	-- flow
r^2	-- correlation coefficient
t	-- t statistic

CONVERSION TABLE

Length

Unit Conversion

1 mm = 0.04 in.	1 in. = 2.54 cm
1 cm = 0.39 in.	1 ft. = 30.48 cm
1 m = 39.37 in.	

Specific Length Conversion

7.5 cm stones x 3 in. stones
20 cm stones x 8 in. stones
6.4 m x 18.3 m x 6.1 m test facility = 26 ft. x 60 ft. x 20 ft. test
1.8 m x 0.9 m x 0.9 m gabion = 6 ft. x 3 ft. x 3 ft. gabion facility
30 m x 0.5 m x 0.5 m test flume = 10 ft. x 1.5 ft. x 1.5 ft. test flume
2.4 m x 0.5 m x 0.5 m test flume = 8 ft. x 1.5 ft. x 1.0 ft. test flume

Head Loss Conversion

0.1 in. = 3.05 cm	2.0 ft. = 60.96 cm
1 ft. = 30.48 cm	2.5 ft. = 76.2 cm
1.5 ft. = 45.72 cm	3.0 ft. = 91.44 cm

Velocity

0.1 fps = 3.05 cps	0.6 fps = 18.29 cps
0.2 fps = 6.10 cps	0.7 fps = 21.34 cps
0.3 fps = 9.14 cps	0.8 fps = 24.38 cps
0.4 fps =12.19 cps	0.9 fps = 27.43 cps
0.5 fps =15.24 cps	1.0 fps = 30.48 cps

Volume

1 cfs = 0.028 cms	5 cfs = 0.140 cms
2 cfs = 0.056 cms	6 cfs = 0.168 cms
3 cfs = 0.084 cms	7 cfs = 0.196 cms
4 cfs = 0.112 cms	

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SECTION I

INTRODUCTION

Several industries, particularly the steam-electric industry, have large requirements for cooling water. All cooling water systems, whether they recirculate the water as in the case of cooling towers or not as in the case of once-through cooling systems, must have an intake system. These intake systems direct water, including the aquatic organisms contained in the water, into the industrial facility. The combination of screening, heat, mechanical action and, in some cases, chemicals added to the cooling water, can result in mortality to aquatic organisms.

The Federal Clean Water Act Amendments of 1972 requires that all cooling water intakes be equipped with the best technology available to minimize the environmental impacts on aquatic organisms. After the Clean Water Act became law, the U.S. Environmental Protection Agency (EPA) and the industrial users of cooling water began to examine and experiment with cooling water intake designs.

One method considered feasible was a rock dike or porous dike. Conceptually, the porous dike would be similar to a stone breakwater and surround the intake. All cooling water would then flow through the rock dike. By selecting a very low approach velocity, approximately 3 cm/sec. (0.1 ft./sec.) and relatively small stones, 7.5 cm (3 in.) to 20 cm (8 in.), it was theorized that the system could act as a physical barrier for large mobile aquatic organisms such as fish and as a behavioral barrier for small weak swimming aquatic forms such as larval fish and microscopic animal plankton.

In order for a porous dike system to be considered a feasible intake, it was necessary to establish that it was in fact a barrier to aquatic organisms and that the system would maintain porosity and not clog.

The research covered in this report was designed to examine these two questions. Specifically, the research was designed to examine the ability of a porous dike to keep zooplankton, larval fish, juvenile fish and adult fish out of industrial cooling water systems. A second objective was to examine the hydraulic characteristics and clogging rates of a porous dike.

SECTION 2

CONCLUSIONS

The results of studies on the hydraulic characteristics of flow through a rock dike have demonstrated that a low flow velocity of 3 cm/sec. can be induced and maintained by a relatively low hydraulic head of approximately 61 cm. Increasing hydraulic head and increasing cross-sectional area result in increased volumetric flow through the stones. In tidal water, the decrease in flow due to decreasing depth is greater than would be predicated based on the reduction of cross-sectional area indicating higher flow resistance in the lower stone sections.

Flow volume induced by a relatively constant head, varied throughout the experiment. Some seasonal trends were evident with lowest flows occurring during the warmest months. Flow volume increased both seasonally and in response to backflushing. Flow volume could be maintained by backflushing.

The major resistance to flow was in the upstream 0.9 m of dike. Organic matter and debris continued to accumulate within the stones through the two-year experiment. Approximately 70% of the fouling material was detritus, including organic debris. Variations in flow appeared to be more correlated to seasonal surface fouling, particularly hydroids and shelled forms than to the accumulation of material within the stones. Approximately 5 cubic yards of silt and debris accumulated downstream of the dike over the two-year test period.

There was no difference in the hydraulic performance between the two stone sizes, 7.5 cm and 20 cm, tested. The fouling organisms in the two stone dikes showed some differences with the 20 cm stone diking having more larger shelled organisms and the 7.5 cm dike having more small attached organisms.

The number of zooplankton per volume of water was reduced by passing through a porous dike. The amount of reduction was less during the colder

months. The reduction was attributed to physical filtration and predation by the fouling community. No evidence, either in the field or the laboratory, could substantiate a zooplankton avoidance response.

The numbers of fish eggs and larvae per volume of water were, in most cases, reduced passing through the porous dike. The reduction in the density of passively drifting fish eggs was attributed to physical filtration and perhaps predation by the fouling organisms within the stones. The reduction in the number of passively drifting larvae such as winter flounder (Pseudopleuronectes americanus) was attributed to physical filtration and perhaps cropping. Winter flounder were shown to exhibit no directional swimming ability or avoidance response in laboratory test flume experiments and the reduction in density observed in the field was, therefore, attributed to filtration or predation. No conclusive evidence was obtained in the field to establish whether or not density differences for actively swimming larvae were due to avoidance or filtration/predation. Laboratory tests did show some species of larvae exhibit a directional swimming ability and avoidance response.

Results of both laboratory and field tests have demonstrated that the porous dike is an effective barrier to juvenile and adult fish. Results indicated that the porous dike may be 100% effective in screening out juvenile and adult fish.

SECTION 3

RECOMMENDATIONS

Further investigation of the role of filtration, predation and avoidance in reducing the density of larval fish would be desirable. Included in such an investigation would be an evaluation of the effect of flow path length on filtration capacity.

Additionally, a larger scale test of a porous dike intake would be desirable to address the specific hydraulic design parameter needed for wide-spread commercial application. Such studies would examine various structural designs that would capitalize on the localized fouling and backflushing potential.

SECTION 4

MATERIALS AND METHODS

GENERAL PROCEDURES

All hydraulic,fouling and field screening performance testing test were conducted at a small-scale porous dike test facility located at Brayton Point Station, Somerset, Massachusetts.

The porous dike test facility (Figure 1) is a reinforced concrete and steel structure measuring 6.4 m wide, 18.3 m long and 6.1 m deep. The chamber is a concrete box, open at the top and front and divided into three cells by wooden timbers. Each cell is 1.8 m wide. A single axial flow pump is located in the back (downstream) end of the box to draw water through the structure. At the front (upstream) end of the box, gabions are placed in the first and third cell. One cell has gabions filled with 7.5 cm stone and the other has gabions filled with 20 cm stone. Each gabion is 1.8 m wide, 0.9 m high and 0.9 m deep. These are placed on top of each other to form a wall approximately 4.3 m high. In the 20 cm test section, there are three rows of gabions making a 2.7 m thick section. In the 7.5 cm test section, there are two rows making a 1.8 m thick section. The center cell is sealed and not in use. Flow is regulated by means of flow-control baffles. Approach velocities were initially set at approximately 3 cm/sec. (0.1 fps). The test facility went into full operation on July 16, 1979.

HYDRAULIC PERFORMANCE

Hydraulic characteristics were measured by recording over the two years of operation the frictional losses through the stones or head loss (h) and the volumetric flow (Q) through the stones. Additionally, special hydraulic studies were conducted to address the efficiency of backflushing and the relationship between increased head and volumetric flow.

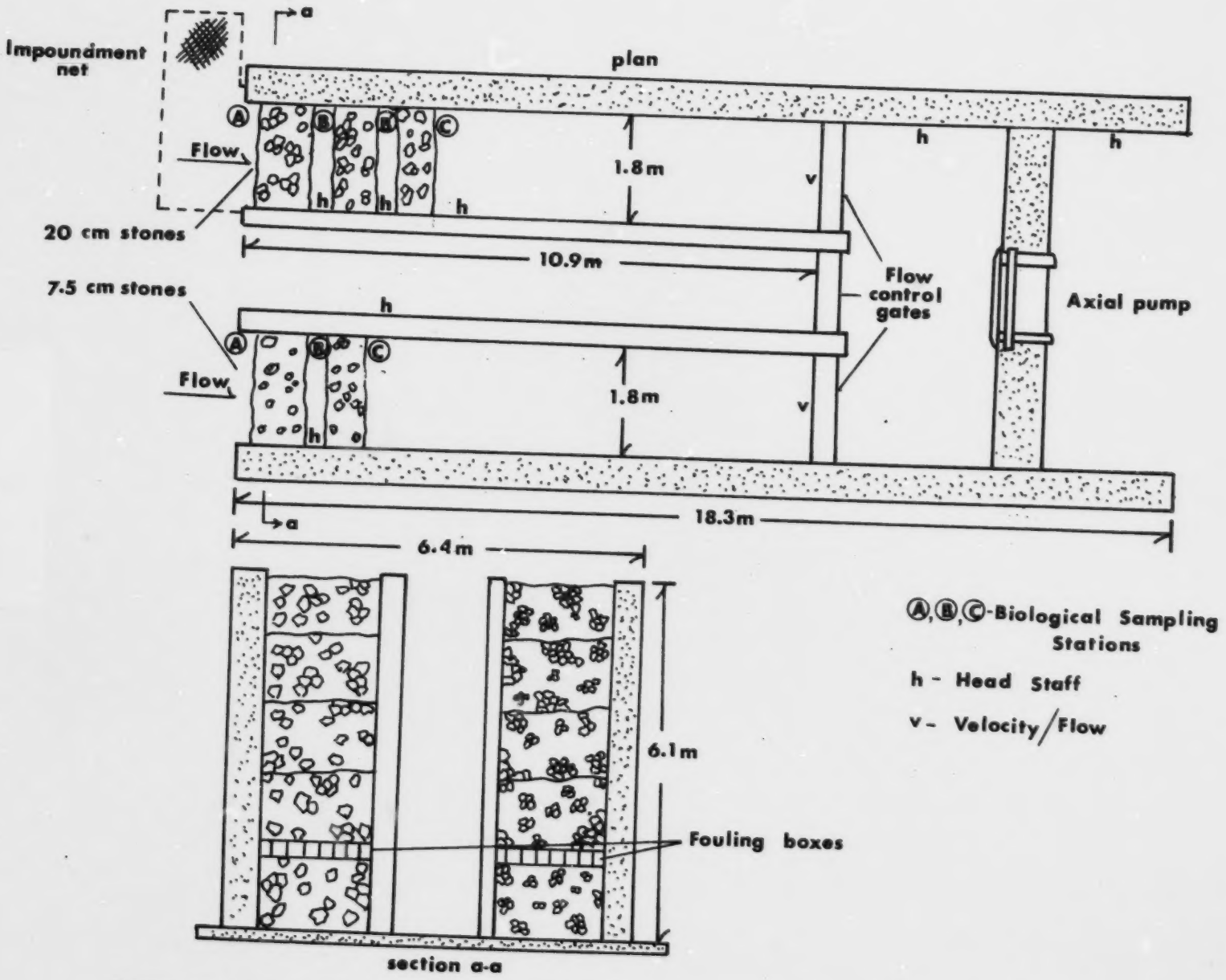

Figure 1. Porous dike test facility.

Head loss was measured by recording the water level at positions upstream of the gabions, downstream of the gabions, downstream of the flow control baffle and downstream of the pump (Figure 1). Additionally, some measurements of h were made in the gabion slots.

Water level was measured with measuring staffs. Staffs were 15 feet (4.6 m) long and divided into 0.1 ft. (3.05 cm) intervals. The staffs were fixed to the walls of the test facility. In the gabion slots, water level was measured using a float and graduated rod. Water level readings were recorded daily each working day. Head loss through the stones was calculated as the difference between the upstream water level and the downstream water level for each test station.

Volumetric flow was measured by recording the velocity of water passing under the known area of the flow control baffle gate. Velocity under the flow control baffle gate was measured in each test section at six fixed locations using a portable current meter. The current meter was fixed to a 6.1 m (20 ft.) pole. The pole was equipped with a mounting bracket which fit into a slot on the baffle gate. This setup insured that measurements were made at the same depth and location on each survey. Velocity measurements were made hourly for one tidal cycle each month.

Two backflush studies were conducted, one in May 1981 and the other in July 1981. During backflushing, water flowed through the stones in the opposite direction. In both studies, the methodology was the same. Starting at time zero, the flow volume and corresponding head loss values were measured throughout a tidal cycle. These flows and heads represented the initial or baseline values. After initial flows were measured, the upstream face of the 20 cm stone section was cleaned using a diver operated pump. The speed of the gasoline driven pump was adjusted to yield a suction which

penetrated no more than 5 cm (2 in) into the dike. After this face cleaning, flow volumes and head readings were taken at 2 to 4 tidal elevations for comparison to the initial Q and h readings.

This face cleaning operation was designed to determine if the increased flow resistance was due to a surface fouling film. After the flow and head readings were taken following the face cleaning, the backflushing was initiated. Backflushing was achieved by turning the axial flow pump off. The facility was allowed to backflush for periods of 1 hour, 2 hours, 6 hours, 8 hours, 16 hours, etc., up to 216 hours (cumulative). After each unit of backflushing, the pump was briefly started and the h and Q readings recorded.

The relationship between increased head differential and flow volume was examined by augmenting the flow rate of the axial flow pump with three gasoline driven pumps. Pumps were added in sequence to increase the head differential and the resultant flow measured.

FOULING RATE

The fouling rate was measured by the change in weight and void space of the gabions. The changes in gabion weight and void space were measured with fouling boxes; a small removable section of the gabions. Fouling boxes were 22 cm x 22 cm x 59 cm stainless steel boxes open at each end and filled with either 7.5 cm or 20 cm stones. These boxes were inserted into drawers placed between the bottom and next to bottom gabion on the upstream and downstream face of each test section at startup. Prior to installation, the weight and displacement volume of each box was measured and recorded. Every three months, one box from the upstream face of each test section was removed and the weight and displacement volume measured and recorded. After each fouling box was removed, all biofouling was identified and measured. All non-living detrital material was collected and weighed.

SCREENING PERFORMANCE

Screening performance was evaluated by both laboratory and field techniques. Field and laboratory screening tests were conducted on zooplankton, larval fish, juvenile fish and adult fish.

LABORATORY SCREENING TESTS

Laboratory screening tests for zooplankton, larval fish and juvenile and adult fish were conducted in a "T" shaped flume (Figure 2). Dimensions of the long arm of the T were 3.0 m x 0.5 m x 0.5 m. The short arm measured 2.4 m x 0.5 m x 0.5 m. A system of valves, located between a 10 hp pump and the flume, controlled both current velocity and direction of flow. Velocity could be maintained between 0.5 and about 30 cm/sec. (0.02 to 1 ft./sec.). The flume was directly connected with fish holding facilities and a mechanical and biological filter system which permitted test animals to acclimate in the same water used in flume experiments. Light level and water temperature were also controlled.

Laboratory Zooplankton Screening Tests

Zooplankton tests were run in the flume with valve openings set to yield an equal volume of water flowing down each arm toward locations B and C (Figure 2). Under this arrangement, water flowed down the short arm (from location A) and at the intersection half of water flowed down the long arm and the other half proceeded down the short arm.

Live zooplankton of known species composition and number were placed in the flume at location A. Under test conditions, a small rock dike 51 cm thick made of 20 cm stones was placed in the long arm at the intersection. Under control conditions, the stones were removed.

The zooplankton introduced into the short arm at location A were captured downstream of the intersection in both the long (C) and short arm (B). Current velocity was maintained at 3 cm/sec.

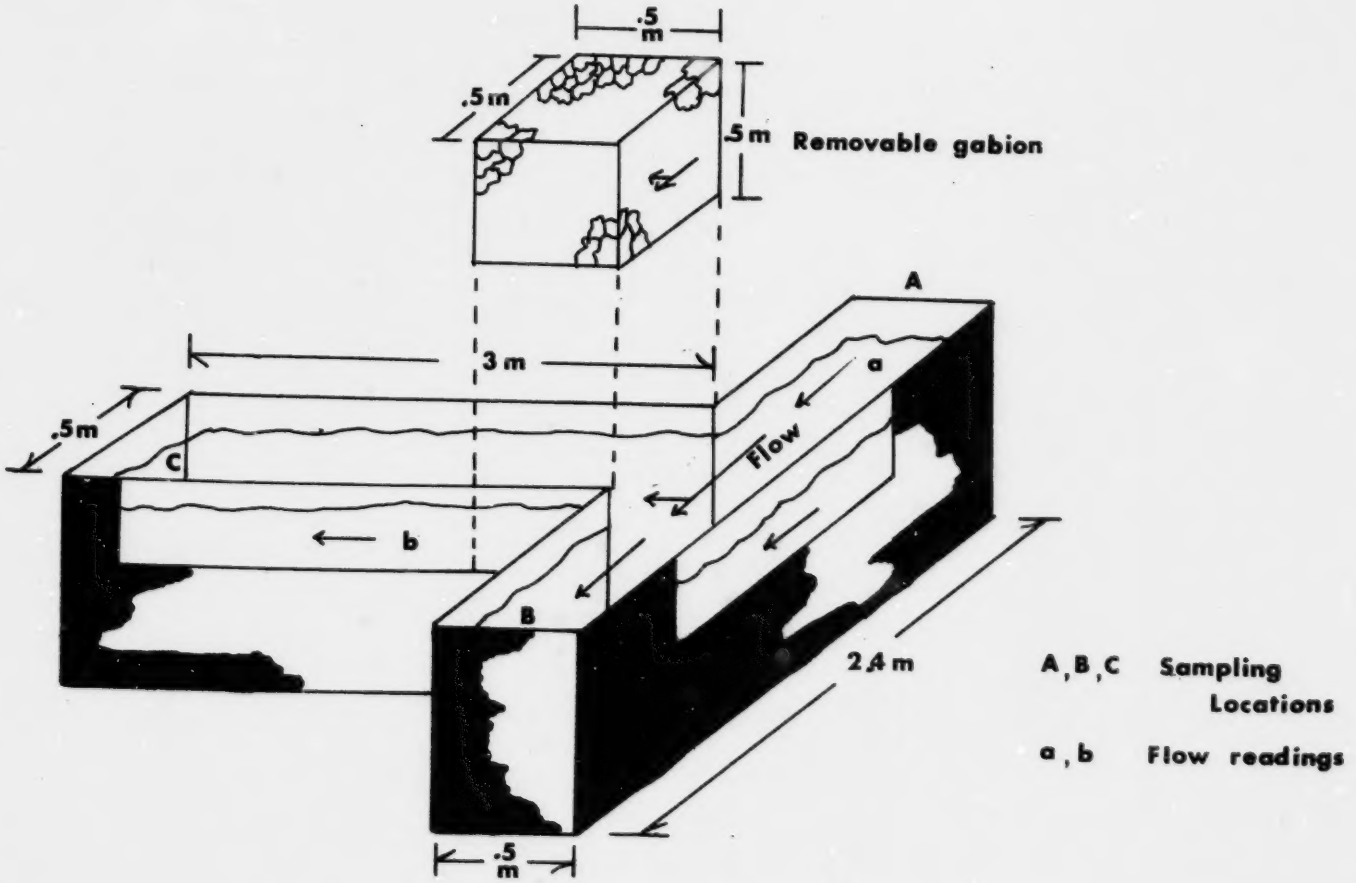

Figure 2. Laboratory test flume.

All preserved samples were analyzed by microscope as to type and number of species present. All density data were converted to the ratio of the number captured over the number introduced before gabion and after gabion. These ratios were used in a paired t-test to determine whether any differences exist between the control and experimental conditions.

Laboratory Fish Screening Tests

Experiments designed to assess the porous dike concept were conducted with the "T" shaped flume (Figure 2). A small rock dike 51 cm thick made of 20 cm stones was constructed where the long arm of the flume joined the short arm. The rocks were carefully packed between stainless steel racks or gabion so that channels through which water could flow unimpeded did not exist along the sides or bottom of the flume. Rock panels affixed to the walls alongside the gabion gave the appearance of a continuous rock wall along the back of the forward chamber. In certain experiments, rocks, similar to those in the dike, were widely scattered on the bottom. In others, gravel, 10 to 15 mm in diameter, was spread in a single layer on the bottom. Water current was directed from A to B (Figure 2) across the face of the rock. Approximately half the volume passed in front of the stone dike and the other half passed through the dike.

To insure that the behavior of test animals was not influenced by an observer, a viewing screen was constructed around the face of the short arm.

Current velocity was generally maintained at 2, 3 or 6 cm/sec. (0.07, 0.1 or 0.2 ft./sec.) measured 1 m downstream of the rock dike. Velocities under 3 cm/sec. were measured by timing the movement of dye or a neutrally buoyant, water-filled ping-pong ball since both flow-meters were insensitive to such low velocities.

Light was generally maintained at 65 lux provided by 4 incandescent lights mounted above the small arm of the flume. Two additional incandescent

lights provided about 45 lux above the long arm. A rheostat allowed reduction of light levels. For 24-hour studies, a timer incorporating a twilight period was used.

Since water temperature in the flume continually increased due to friction between the water and flume surfaces, temperatures were maintained within 2.5°C of the initial acclimation temperature by exchanged with cooler, ambient seawater or exchanged between the flume and a separate insulated reservoir containing two cooling units.

The basic experimental procedure consisted of introducing small fish or larvae into the short arm of the "T" at location A and recording their behavior for periods of from 30 minutes to several hours. Before release, each sample of fish was acclimated in the current for 20-30 minutes in either a screened 8-liter pail or screened 1-liter beaker with removable bottom. The number of individuals per test ranged from one or two in the case of larvae, which were visually difficult to follow, to 75 in cases where fish were available in large numbers. Most tests consisted of fish of similar size obtained by beach seine or otter trawl, or by laboratory repairing. In cases where the same fish were held for repeated observations, at least seven days elapsed before fish were used again.

An additional study was conducted to observe the filtering capacity of the stone in the porous dike test facility. A fouling box containing 20 cm stone was removed from the test facility at Brayton Point, transferred to the flume and placed at the intersection. The leading edge of the box was fitted into a wooden panel cut to fit the exact dimensions of the box mouth so that all water flowing down the long arm of the flume passed through the box. Spaces between the box and panel were filled with oakum. A small 0.33 mm mesh net with cod end was tied to the back edge of the box to catch all material passing through it. Flow rate through the box was set at 3 cm/sec.

Samples of preserved larval winter flounder and labrid eggs were released at the face of the box while the flume was operating. Flow was maintained for seven minutes at which time the flume pump was shut off, the net removed, washed down and the sample preserved until counted.

Samples consisted of the following - stage I larval flounder n = 200, two replicates; stage II flounder n = 200, three replicates; stage III flounder n = 200, three replicates, for a total of 1,600 larvae and labrid eggs n = 200 (diameter = 0.7-1.1 mm), three replicates, for a total of 600 eggs. After all the larvae and egg samples were introduced to the flume, the net was reattached to the box and the flow was increased to approximately 8 cm/sec. for seven minutes to flush the box. This entire procedure wsa repeated in an identical manner using a fouling box filled with clean 20 cm stone.

Field Screening Tests

All field screening tests for zooplankton and larval, juvenile and adult fish were conducted at the porous dike field test facility (Figure 1).

Field Zooplankton Screening Tests

Zooplankton field studies were conducted on 90 dates between July 1979 and July 1981.

Evaluation of the effectiveness of a dike in reducing zooplankton entrainment was based upon comparisons of the population density at locations upstream, downstream and within the dike. Sequential sampling was carried out during daylight at three locations (A, B and C) for both the 7.5 and 20 cm rock channels (7.5 A, 7.5 B, 7.5 C and 20 A, 20 B, 20 C) (Figure 1) eight times during each sampling day. Collections at each pair of locations (7.5 A - 20A, etc.) were made simultaneously using identical gear for both channels. Each sample was taken by pumping 500 liters of water through #30 (59 u) mesh nets using gasoline-powered pumps. To insure that all of the water column was

sampled, one-third of each sample was pumped from the bottom third of the water column, from mid-depth and from the top third of the water column, eight samples from each sampling location in each channel were combined into a single composite sample which represented the zooplankton population for that location. During the first year, sampling was conducted on a weekly basis with 48-hour day-night sampling being carried out once a month. During the second year, sampling was reduced to a biweekly regime with a 24-hour day-night sampling conducted once a month.

In the laboratory, each sample was reduced in volume to a concentration between 300 to 500 organisms per milliliter, and three 1 ml aliquots were removed and analyzed as to type and number of each organism present. To facilitate analysis, volumes were kept under 1,000 m^{3}. If necessary, samples were split with a plankton splitter.

Data were analyzed for density differences.

Field Larval Fish Screening Tests

Ichthyoplankton densities on the upstream and downstream sides of the porous dike were sampled between August 1979 and July 1981 during the months of March, April, May, June, July and August - months when ichthyoplankton were most abundant.

Ichthyoplankton samples were taken with a gas-driven trash pump using 10 cm intake and discharge hose and a 0.33 mm mesh plankton net. To improve the condition of ichthyoplankton, the last 2.4 m of discharge hose was increased to 15 cm diameter hose and the net was submerged. Pumping duration per sample ranged from 15 to 30 minutes depending on the abundance of ichthyoplankton in the samples. During each pumping period, the intake hose was moved at set intervals so that surface, mid-depth and near-bottom were sampled equally.

Pumping volume was determined by recording the time necessary to fill a 757-liter box suspended in the same position as the sampling net. A tachometer,

accurate to within ± 2%, was used with the pump to assure operational accuracy between sampling and calibration. At 3,200 rpm, the pump delivered 2.11 m^3 per minute; therefore, 15 to 30 minute samples represented between 31.7 and 63.3 m^3 of water.

In 1979 and 1980, sampling was conducted two days per week, one day in the 7.5 cm channel, one day in the 20 cm channel. In July and August 1980, sampling frequency was increased to three days per week to compensate to some extent for time lost when the facility was shut down for repair. In 1981, sampling was again conducted two days per week with one (March - mid-June) or two (mid-June - July) night sampling periods conducted in addition to the day periods. As in 1980, collection dates alternated between 7.5 cm and 20 cm channels whenever possible.

On each sampling day, samples were taken at Locations A and C (Figure 1). Generally four to ten sets of samples were taken during each day depending on pumping duration. Although the original sampling design included collecting within the slots between gabions (B positions in Figure 1), a problem developed when the weight of stone caused the gabions to bulge into the slots. In the 20 cm stone channel, the slots were so narrow that the 10 cm hose could not be lowered into the water. Initially, sampling was possible at position B of the 7.5 cm channel, but only near high tide because the hose could not always be fitted far enough into the slot to reach water level. Beginning in May 1980, an additional intake hose was obtained for the B position of the 7.5 cm channel. This hose was worked into the slot and left permanently in place so that samples could be taken regularly at that position. Because the hose could not be raised or lowered in the slot, sampling was restricted to one depth - approximately 1.2 m above bottom.

All samples were preserved in 10% Formalin and returned to the laboratory for microscopic analysis. Fish eggs and larvae were identified to the lowest distinguishable taxonomic category and counted.

Data were analyzed for density differences.

Field Fish Screening Tests

Field finfish experiments were conducted at the porous dike between September 1979 and July 1981 using the impoundment enclosures depicted in Figure 1. The enclosures were constructed of 4.7 mm nylon mesh including a complete bottom, but were open where they joined the dike. Each enclosure was 4.3 m high. The mouth of each enclosure was held open by a metal frame which fit tightly within U-shaped slots in front of each channel. The offshore section of each net was held in place by a system of haul lines and anchor poles. The head ropes were fitted with floats and were pulled tightly to keep them above high water.

Fish to be tested were collected by beach seine, otter trawl, lift net or on the revolving screens at Brayton Point Power Station. Typically, the nets were set, a known number of test fish were released in each enclosure, and the system was left undisturbed for a period of time ranging generally from 24 to 72 hours. At the end of the test period, the nets were hauled, mouth first, and the fish remaining inside were counted and measured.

Fish were selected by size such that they were too large to escape through the enclosure meshes and yet small enough to enter the spaces between rocks of the dike if they chose to do so. During the winter months, tests were run whenever fish were available and weather permitted. On many occasions, only one net was set either because sufficient numbers of fish were not available to stock both nets or because it would interfere with ichthyoplankton sampling at the dike.

Since early in the study, it was not possible to determine whether missing fish had escaped or entered the stones, a method of seining the downstream section of each channel was developed in July and August 1980. All fish introduced to the impoundments from that point on were finclipped so they could be easily identified if subsequently collected in the downstream channels.

The seine measured 3m x 3 m was constructed of 4.7 mm delta mesh and was lashed along the vertical edges to two 3 m long wooden poles. The bottom edge of the seine was weighted with chain; the bottom of each pole was weighted with lead. To assist in hauling the seine over the length of the channel, haul lines were fixed to the top and bottom of each pole. To confine fish in the channels during seining operations, 4.7 mm mesh screens were constructed to slide down in slots fixed to the channel walls in front of the openings under the baffle gates. Generally, three seine passes were made whenever an impoundment test was conducted.

SECTION 5

RESULTS AND DISCUSSION

HYDRAULIC PERFORMANCE

Head Loss (h)

Head loss data can be evaluated for the following:

1. Relationship to tidal height.
2. Relationship to flow (Q).
3. Trends over time.
4. Development through the stone gabions.

Theoretically for flow through a fixed cross-sectional area, the amount of flow should be proportional to the square root of the hydraulic head. In other words, to increase the flow through a fixed area there must be a squared increase in the head differential.

Additionally, for a fixed flow, the loss or head drop should be inversely proportional to the square of the cross-sectional area. The simplest mathematical expression for these two relationships are as follows:

1. For a fixed cross-section area

$$Q = K\sqrt{h}$$

Q = flow
K = constant
h = head differential

2. For a fixed flow

$$h = \frac{K}{A}$$

h = head differential
K = constant
A = area

The porous dike test facility was located in tidal water (mean tidal amplitude 4.0 ft.). As such, the mean cross-sectional area of the porous dike was continuously oscillating with the rise and fall of each tide. Figure 3, a scatter plot of tidal height vs. hydraulic head differential, indicates that there was no correctional ($r^2 = 0.05$) between cross-sectional

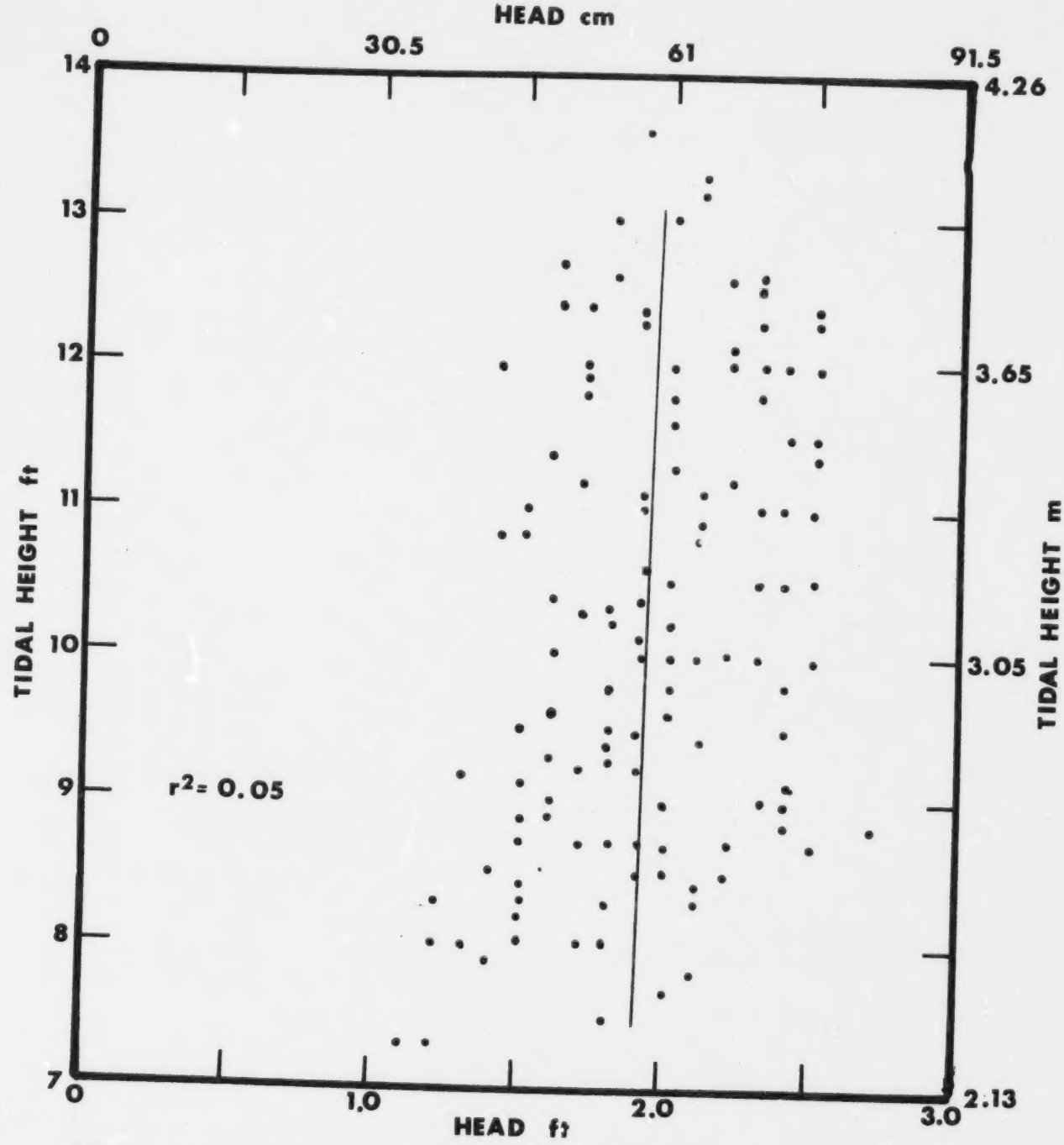

Figure 3. Tidal height vs head for 8 in stones.

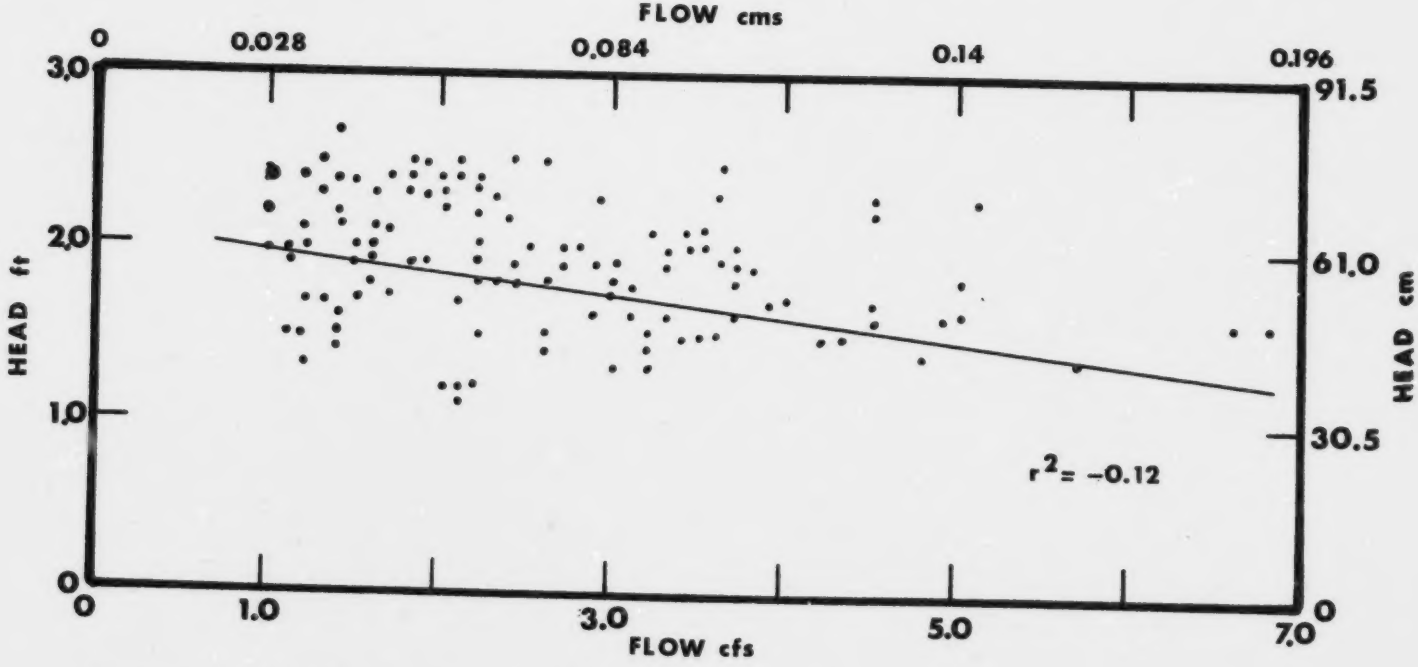

Figure 4. Hydaulic head vs flow through 8 in stones.

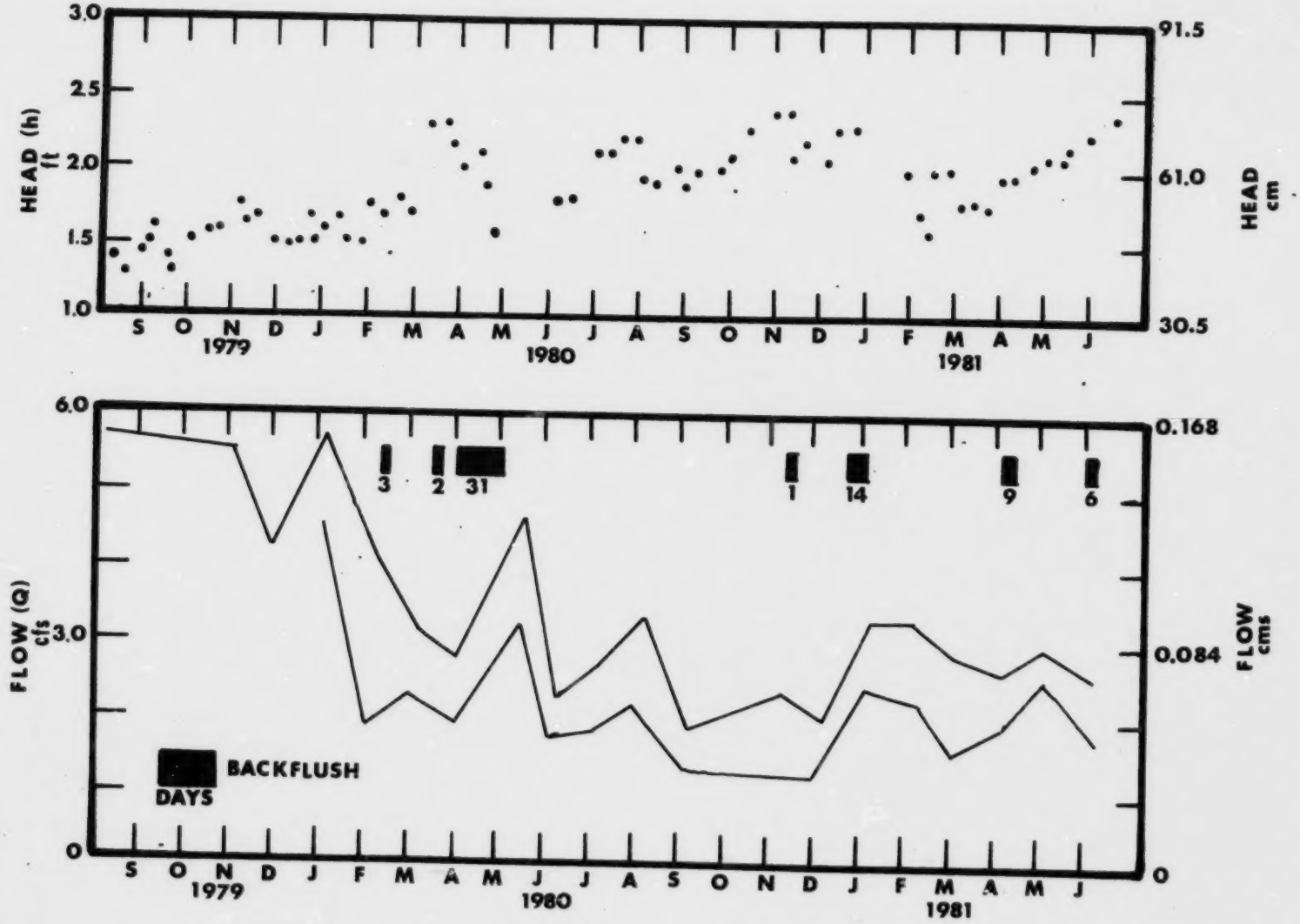

Figure 5. Hydraulic head and flow through 3in test stones.

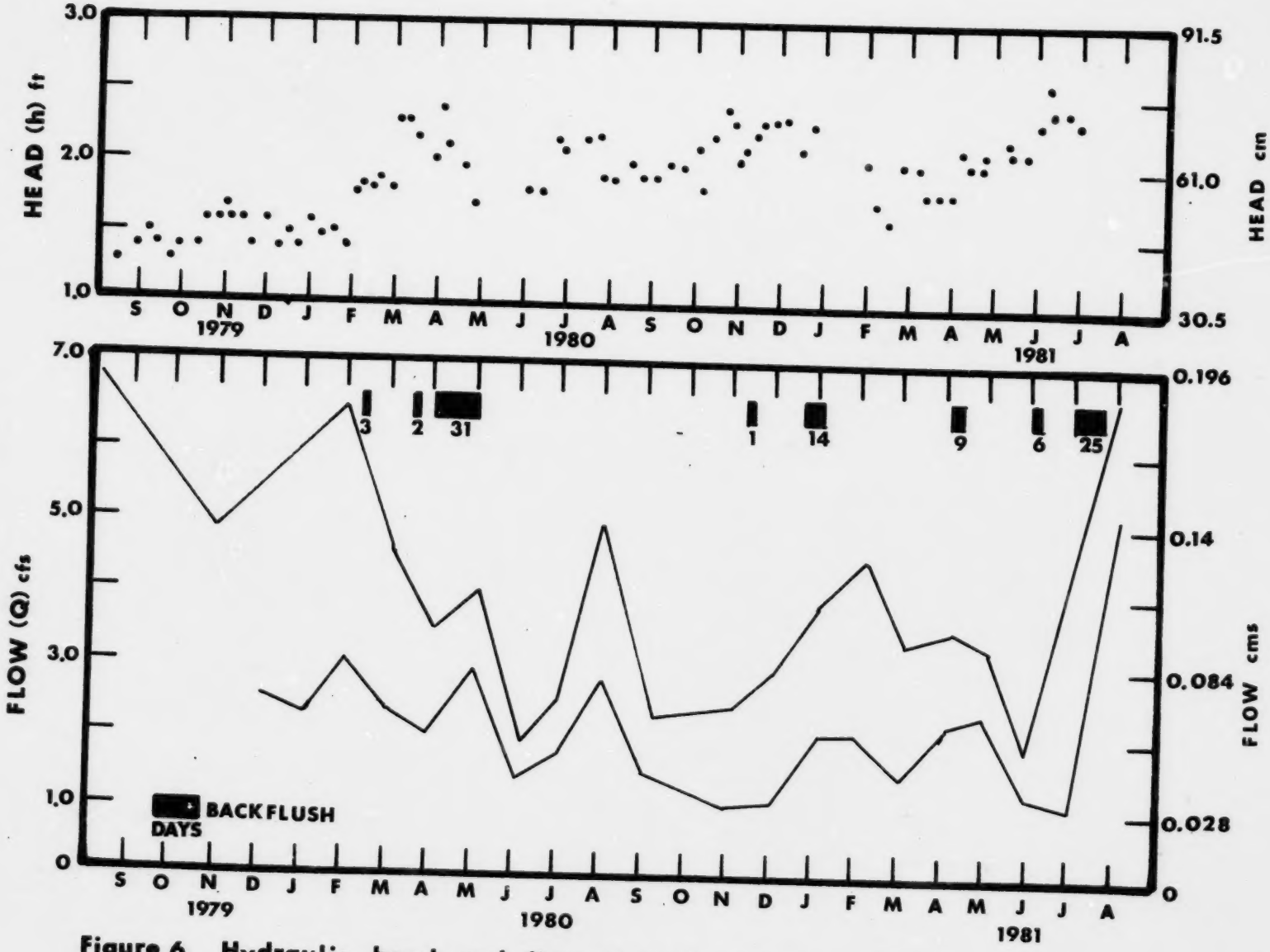

Figure 6. Hydraulic head and flow through 8 in test stones.

area and head. The hydraulic head at high tide (greater cross-sectional area) was nearly identical to the hydraulic head at low tide (smaller cross-sectional area). This suggests that flow must not have remained fixed, but increased with increasing cross-sectional area. This relationship will be developed more fully in the flow section. Since neither Q nor cross-sectional area (A) remained fixed, it is not surprising to find as plotted in Figure 4 that there is little correlation between hydraulic head and flow ($r^2 = -0.12$). The trend in hydraulic head over the two-year test period is presented in Figures 5 and 6. These figures are plots of the weekly average hydraulic head. The trends in hydraulic head for the 7.5 cm and 20 cm stone test sections were identical.

Starting in September 1979 and continuing for the first 7 months of operation, losses ranged around 1.5 $\pm$ 0.2 ft. (45.7 $\pm$ 6.1 cm) level. In April 1980 (8 months after startup), the head values rose to the 2.0 + 0.2 ft. (60.8 $\pm$ 6.1 cm) level. Values continued to fluctuate around the 2.0 to 2.5 (76.2 cm) ft. level for the remainder of experiment. The rise in head loss during April was consistent with the spring fouling growth.

Decreases in hydraulic head occurred during the experiment after five of the backflushes, indicating the backflushing was an effective method of reducing frictional loss in the system. The effect of backflushing will be covered in a separate section. Head loss also decreased when there was no backflush. The reason for these decreases was assumed to be due to a natural succession or die off of fouling organisms.

The development of head loss through the 2.7 m flow path length of porous dike is given in Figure 7. This plot is for the period April 18, 1981 through July 17, 1981, and is the only daily internal head loss data available. Some internal head loss readings were taken during monthly 24-hour flow

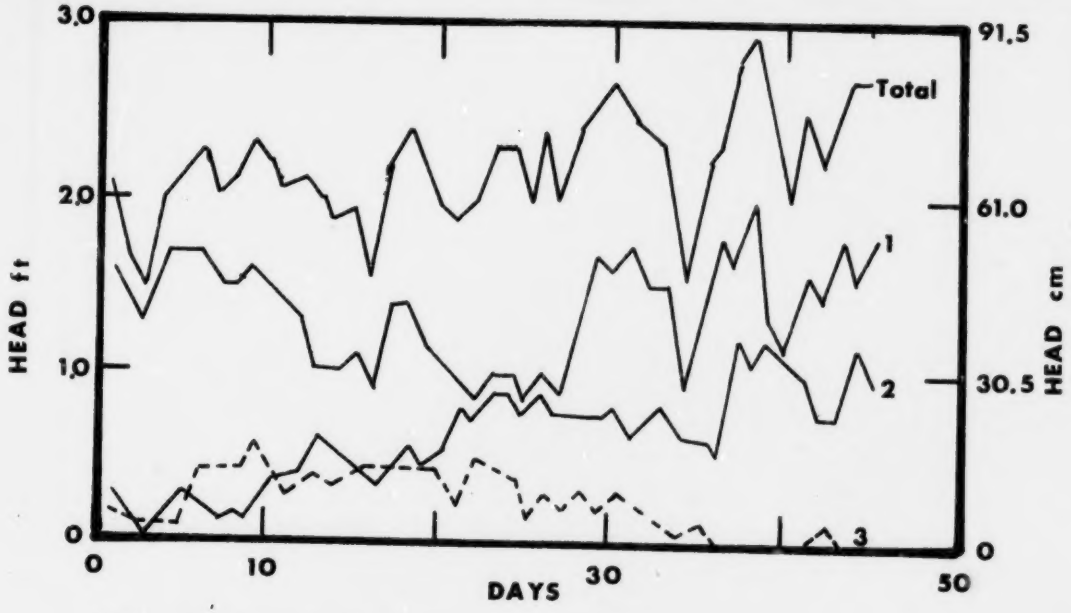

Figure 7. Actual head loss per gabion.

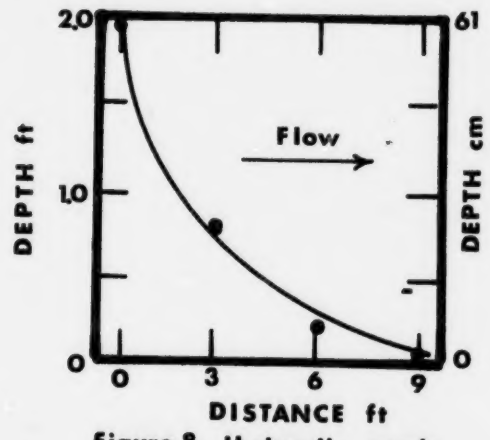

Figure 8. Hydraulic grade line.

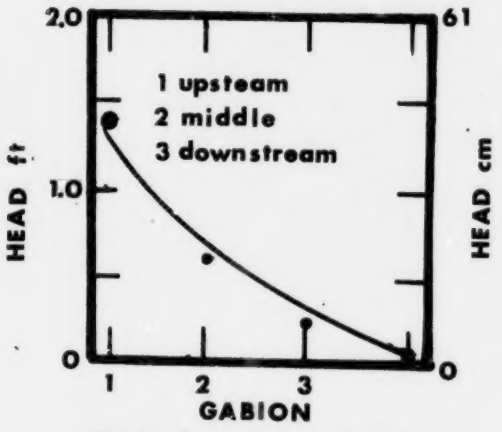

Figure 9. Average head loss per gabion.

surveys and this data shows the same pattern. Approximately 64% of the total head loss occurs in the first upstream 3-foot gabion section while 27% of the hydraulic loss occurred in the middle section. The remaining 9% of head loss occurred in the last downstream gabion.

The assumed hydraulic grade line through the three sections of gabions is given in Figure 8. The hydraulic grade line shows proportionally how much of the head loss occurred in the first upstream gabion and how little of the head loss occurred in the last downstream gabion.

The average amount of head loss contributed by each section increased in a nearly linear fashion moving from the most downstream gabion to the most upstream gabion (Figure 9).

Volumetric Flow (Q)

Flow data can be evaluated for the following:

1. Relationship to tidal height.
2. Relationship to head.
3. Trends over time.

All flow and head loss data collected during 24-hour surveys are given in Appendix, Table 1.

The volumetric flow of water through the porous dike was strongly correlated ($r^2 = 0.74$) to the tidal height (Figure 10). This is not surprising since the hydraulic head remained relatively constant over time, but the cross-sectional area fluctuated with each tidal exchange. Essentially, the axial flow pump used to draw flow in this experiment maintained a constant head while pumping less volume at low tide and more volume at high tide.

The relationship between flow head and tidal height is described by the following equation:

$$Q = K.\sqrt{h}.A$$

Q = flow
K = flow coefficient
h = head
A = cross-section area

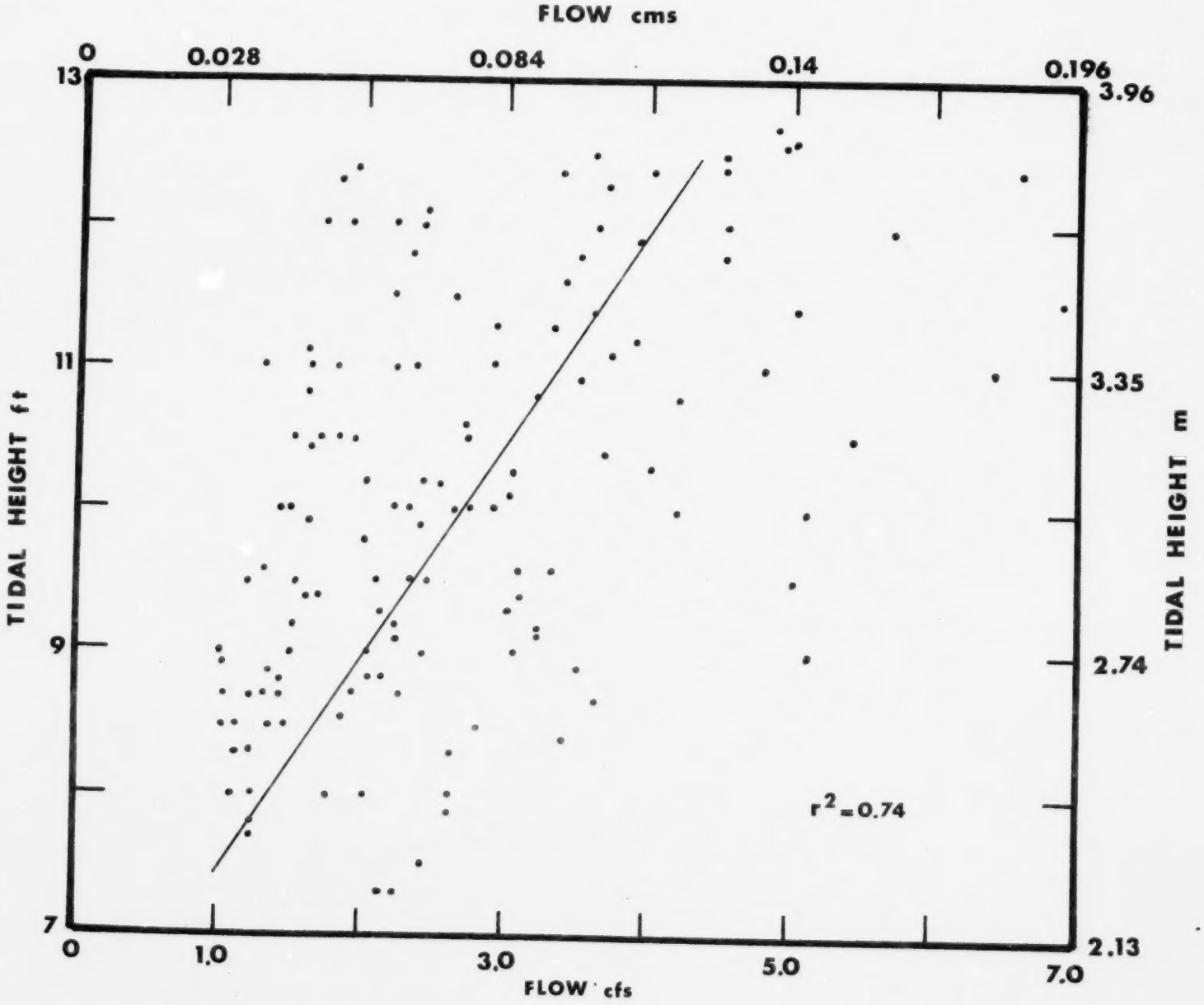

Figure 10. Tidal height vs flow through 8 in stones

As the area (A) increases and if the head (h) is constant, then the flow (Q) should be directly proportional to the area. However, as can be seen in Table 1, Q increased by a greater amount than would be predicted by the increasing area. This means that the flow coefficient, K, for the high tide condition must be greater than the K for the low tide condition. This phenomenon is believed due to differential fouling above and below the mean tide level. As stated previously, there was little correspondence between the h and Q.

A special study conducted in July 1981 was designed to examine the relationship between increasing head and flow. Three additional pumps were used to augment the flow produced by the axial flow pump.

During the experiment, the auxiliary pumping could only increase the head by a maximum of 0.6 ft. However, these small increases in head produced relatively large increases in flow (Table 2). For example, at low tide, a 4.0 ft. increase in the head doubled the flow and at high tide a 0.3 ft. increase in the head increased the flow by 73%.

The amount of water flowing through the porous dike has varied during the two-year experiment as can be seen in Figures 5 and 6 and Appendix, Table 2. Several items are noteworthy:

1. Some seasonal trends are suggested. Flow declined each December and July and tended to increase each March and September.
2. Backflushing increased the flow volume.
3. The flow at the end of two years of nearly continuous operation was almost identical to the flow at startup, April 1979.

The increase in flow seen in September 1981 followed a 25-day backflush. The increase in flow from this backflush was greater than the increase in flow

TABLE 1. TIDAL VARIETIES IN FLOW COEFFICIENT $(k)_{1)}$

Date	Tidal Height (ft.)	Area (A) ($ft.^2$)	h (ft.)	Q cfs	Q/A^x 10	K
3/6/80	8.0	48	1.7	1.7	3.5	.027
	9.2	55.2	1.9	2.2	3.9	.028
	10.2	61.2	1.8	2.4	3.9	.029
	11.1	66.6	1.9	3.7	5.6	.040
4/28/80	9.0	54	2.3	2.0	3.7	.024
	10.0	60	2.2	2.2	3.8	.025
	11	66	2.5	2.4	3.6	.023
	12.6	76	2.3	3.6	4.7	.031
7/10/80	8.0	48	1.5	1.1	2.3	.018
	9.2	55.2	1.7	1.5	2.7	.021
	10.0	60	2.0	1.5	2.5	.018
	10.8	64.8	2.1	1.7	2.6	.018
	12.0	72	2.3	1.9	2.6	.017
	13.0	78	2.0	2.8	3.5	.025
	13.6	81.6	1.9	3.6	4.4	.032

1) $K = \frac{Q}{\sqrt{h}.A}$

TABLE 2. VARIABLE HEAD INDUCED FLOWS

Tidal Height (ft.)	No. of Pumps 1)	h (ft.)	Q (cfs)
7.8	1	1.8	0.9
7.8	2	1.9	1.4
7.8	3	2.1	1.6
7.8	4	2.2	1.8
8.4	1	2.4	1.8
8.4	2	2.5	1.8
8.4	3	2.5	1.8
8.4	4	2.7	2.2
9.2	1	1.9	1.8
9.2	2	1.9	2.7
9.2	3	2.0	2.7
9.2	4	2.1	3.2
9.5	1	2.6	2.3
9.5	2	2.6	2.3
9.5	3	2.7	2.5
9.5	4	2.9	2.5
9.7	1	1.7	2.2
9.7	2	2.0	1.8
9.7	3	2.2	1.8
9.7	4	2.3	3.4
10.4	1	1.8	2.2
10.4	2	2.0	3.2
10.4	3	2.1	3.8

1) Pumps

1. Axial flow pump
2. Axial flow pump plus 1 1200 gpm pump
3. Axial flow pump plus 2 1200 gpm pumps
4. Axial flow pump plus 3 1200 gpm pumps

from any other backflush. This large increase may be due to a combination of backflushing and a seasonal increase in flow. A similar increase in flow was noted in September 1980 with no backflushing. These flow increases in September may be due to a seasonal die off of some of the fouling community.

It should be noted that all the flow data presented so far was based on velocity readings taken at the upstream face of the flow control baffles. Velocity readings taken in this area under-estimated the velocity since not all flow vectors were horizontal and the velocity meter reads only the horizontal velocity component.

Velocity vectors downstream of the flow control baffle were more uniformly horizontal and, as such, a higher flow estimate was obtained when estimating flow from these readings. Based on a number of upstream and downstream velocity readings, it was found that the average velocity downstream was 2.3 times higher than the velocity upstream. The flow estimated from downstream velocities was, therefore, 2.3 times higher than the flow estimated from upstream readings. Finally, in calculating the actual flow through the stones, the estimated flows from downstream velocity readings must be reduced by 60% to compensate for the restriction under a baffle gate. Therefore, flows estimated from upstream velocities must first be increased by 2.3 and then reduced by .6 to yield an estimate of the actual flow.

These calculations have not been done in Appendix Tables 1 and 4 and Figures 4, 5, 6 and 10, and are only necessary in estimating the dike size needed to accommodate a given flow.

As previously mentioned, backflushing resulted in increased flow and decreased head. Eight backflush episodes occurred during the experiment. Two of these were planned experiments, while the other six were due to pump repairs or structural changes requiring pump shutdown. Results of the two

backflush experiments are given in Table 3. The hydraulic head driving the backflush ranged between 0.5 and 1.0 ft. (15.2 and 30.4 cm). These results suggest that for backflushes of 6 or 9 days, the optimum cleaning occurs after 4 to 48 hours. It is interesting to note that neither planned backflush experiment produced the degree of improvement seen in two of the unplanned experiments. This could be due to a seasonal difference or simply a matter of duration. Some of the unplanned backflush episodes were for longer periods than the planned backflushes. After two of the unplanned backflush episodes, June 1980 and September 1980, large amounts of shell fragments were found on the downstream side of the dike and many dead barnacles were seen on the face of the gabions.

FOULING RATE

The changes on fouling box displacement volume and weight are given in Table 4 and plotted in Figures 11 and 12.

It is interesting to note that the gross weight increases have a range of some three times larger than the biomass of the material which was removed from the boxes for analysis in the laboratory. There are various factors which may account for such differences: sediment, trapped in the rock crevasses or by the accumulated biomass, would be present during weighing, but would likely be washed out during the subsequent hydraulic measurements; water present during weighing, but lost during transfer of the rocks; part of the biomass, which may not get scraped from the rocks for laboratory analysis.

The plots of the percentage changes in displacement volume, gross weight, and biomass vs. time in the water indicate that bioaccumulation did not reach a peak or stabilize over the two-year study period. The curve which best fits the plot of displacement volume change in either channel with time is

TABLE 3. MAY BACKFLUSH RESULTS[1)]

Hours of Backflushing	Change in Flow (cfs)	Percent change in Flow (cfs)
0	0	0
Face Cleaning	0	0
1 hr	0.3	3.0
4 hr	0.7	8.4
8 hr	0.3	5.0
19 hr	0.5	8.3
22 hr	0.8	13.3
48 hr	0.8	12.5
71 hr	1.6	26.7
140 hr	0.1	1.2
216 hr	1.1	12.6

1) Tests on 8 in. stones

JUNE BACKFLUSH RESULTS[1)]

0	0	0
Face Cleaning	.9	82
1 hr	1.4	127
4 hr	1.7	131
24 hr	1.2	80
25 hr	1.0	90
26 hr	1.1	138
27 hr	0.7	64
44 hr	2.4	100
47 hr	1.0	48
49 hr	0.5	33
137 hr	0	0

1) Tests on 8 in. stones

Table 4. Percentage Change in Fouling Tube Weight and Displacement Volume

Stone Size	Time (Months)	3	6	9	12	18	21	23
		Percent Increase in Weight						
3" Stones		7.7	10.1	9.8	8.9	15.9	25.1	18.6
8" Stones		5.3	6.5	10.2	12.8	20.8	21.9	26.0
		Percent Increase in Displacement Volume						
3" Stones		19.6	28.4	28.3	29.3	40.2	--	--
8" Stones		16.1	19.6	31.2	34.7	41.2	--	--

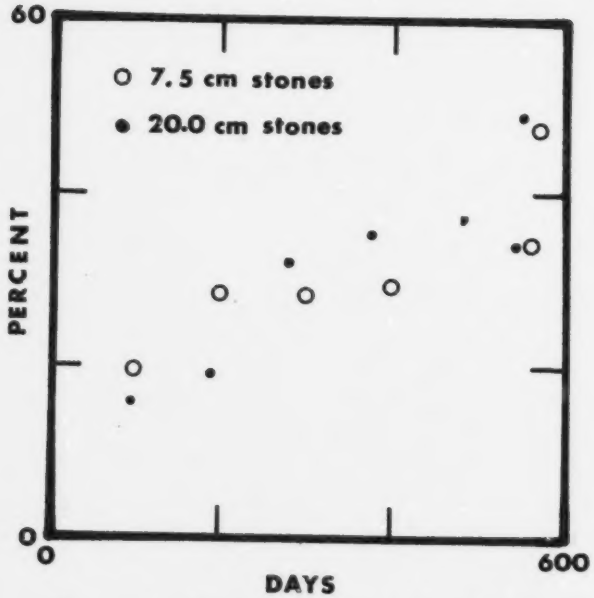

Figure 11. Percent change in displacement volume.

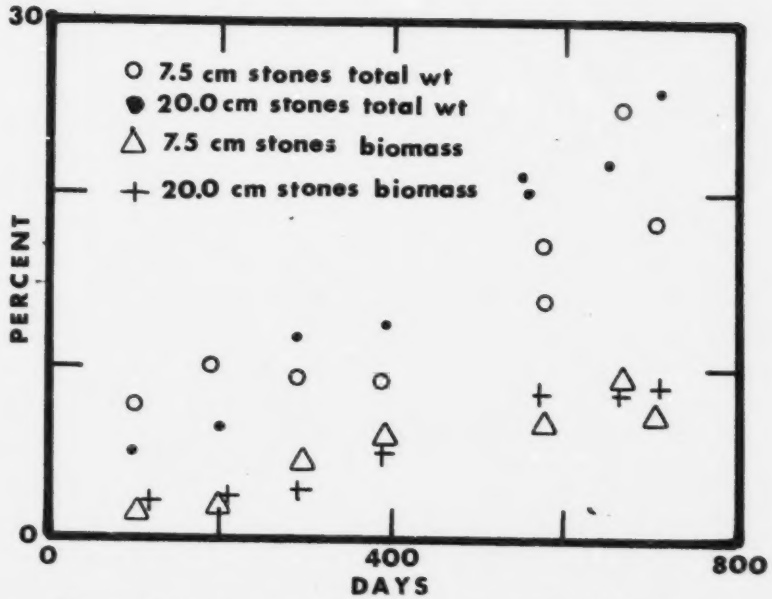

Figure 12. Percent change in total weight and biomass.

parabolic ($y = ax^b$). The curve which best fits the plots of gross weight change and actual biomass change in either channel with time is a straight line.

The analysis of the fouling material is summarized in Appendix Table 3 and data is presented as weight of species or groups, rather than as numbers.

The first examination of the 7.5 cm box was for December 1979, approximately three months after its insertion into the porous dike. The anemone, Metridium senile, was abundant immediately, attaching directly to the rocks, as did the tunicate, Molgula sp., also known as "sea grapes." The first polychaetes to find protection in the rock spaces were tiny syllids, Brania clavata and Autolytus sp. Barnacles appeared, as did the scavenging crab, Neopanope sayi, which is often found in areas of fouling.

The following spring 1980, showed an increase in barnacles, N. sayi and Molgula sp. Since the calcareous shells of barnacles remain attached after the animals die, and continue to contribute to fouling, no distinction was made between live and dead barnacles in the analysis and the number of live may not have actually increased with time. With the coming of warmer winter, the hydroids and bryozoa began to increase. The two polychaetes, B. clavata and Autolytus sp., which were dominant in the winter sampling, were replaced by the prolific fouler, Polydora ligni, which builds mud tubes. The large polychaete, Nereis succinea, was present throughout the sampling period, there being ample food, such as amphipods or other polychaetes, for this predator in the spaces between the rocks.

In the summer of 1980, P. ligni became established as the dominant polychaete. Barnacles remained numerous, and the large attached species of gastropod, Crepidula plana and C. fornicata, began to find niches. A large number of juvenile Mytilus edulis appeared in June, comprising 33% of the weight increase for that month.

In the fall 1980 sample, Mytilus rapidly declined, but never disappeared. The ever-present polychaete, Hydroides dianthus, became more evident for the same reason as barnacles as they build permanent calcareous tubes which remain after the worm dies. Hydroids and bryozoa, were much more abundant and provide a habitat for the clinging caprellid amphipod, which was the numerically dominant species of amphipod in this season. Due to their size, barnacles, Molgula sp. and Neopanope sayi, continued to account for most of the biomass.

The next sample was not taken until spring of 1981. Polychaete recruiting, which would have stopped during the winter, began again and numbers were high; however, due to their small size, the percent of biomass is always low. Crepidula spp. remained abundant in the sample, primarily due to the presence of shells in the box. Two species of amphipods, Jassa falcata and Corophium spp., became the numercially dominant amphipods and remained so throughout the summer. Barnacles were still plentiful, but Molgula sp. seemed to have died over the winter. The detrital accumulation was high, containing large amounts of dead hydroids and bryozoa. Tubes of Hydroides dianthus were still increasing.

Mytilus edulis juveniles began appearing in the summer 1981 samples. Crepidula spp. and barnacles remained high in biomass as did Hydroides dianthus. Neopanope sayi represented the lowest percentage thus far, and amphipods were few, while Molgula sp. was beginning to increase again.

When a downstream box was sampled in April 1981, it showed no appreciable difference in community composition or in weight gain when compared with the upstream boxes.

Throughout the study period, the samples showed a natural seasonal fluctuation of species recruitment as well as a steady accumulation of permanent material, such as barnacle shells, mollusk shells and calcareous worm tubes.

The first examination of the 20 cm boxes in December 1979 showed some differences from the 7.5 cm box. The anemone, Metridium sp., was also present as were the numerically dominant polychaetes, Brania clavata and Autolytus sp. Barnacles, The mud crab, Neopanope sayi, represented the greatest percentage of fouling by weight; however, caprellid amphipods were very abundant, comprising 5.09% of the biomass. In addition, there was an accumulation of hydroids and other detrital material providing a habitat for the clinging amphipods. At this time, the tunicate, Molgula sp., was scarce, and the tube worm, Hydroides dianthus, was present, but not very abundant until the end of the sampling period.

There was little change in the spring 1980 sample except for a decrease in amphipods over the winter.

In the summer 1980 sample, Polydora ligni had become the numerically dominant polychaete and remained so throughout the two-year period. Mytilus edulis juveniles appeared in great numbers, comprising 30.8% of the biomass. Microdeutopus anomalus became the dominant amphipod, although its percentage of occurrence was very small. Barnacles showed a large increase over the spring, but Neopanope sayi decreased as it did in the 7.5 cm fouling box.

In the fall of 1980, Mytilus had almost disappeared and caprellid amphipods had regained dominance, comprising 29.8% of the biomass, which, owing to their tiny size, amounts to a considerable number of animals. N. sayi and Molgula sp. increased briefly.

The next samples to be examined were in the spring of 1981, and Crepidula spp., the large attached gastropods, began to appear and remained abundant as their shells accumulated after the organisms died. Corophium sp. and Jassa falcata became the numerically dominant amphipods as spring recruitment began. Molgula sp. was again scarce as it died over the winter. The amount of dead hydroids and other detritus had grown over the winter to comprise 65-76% of the biomass.

In the summer of 1981, Hydroides dianthus was suddenly very abundant at 8.14% of the biomass. Mytilus edulis and Crepidula spp. were also numerous, but amphipods were very scarce for some unknown reason. Barnacles remained one of the primary foulers and Molgula sp. reached a new high not seen the previous year of 20.4% of the biomass.

The single downstream box sampled in April 1981 showed no appreciable difference in community composition, but did exhibit less of a weight increase when compared with the upstream samples.

The community composition seemed to follow natural seasonal fluctuations, and increases from permanent remains of barnacles, shells, detritus and debris were seen.

The 7.5 cm rocks had a much greater surface area, permitting the attachment of a greater number of small organisms than in the 20 cm boxes. For example, the small calcareous tube worm, Hydroides dianthus, was always much more abundant in the 7.5 cm rocks than in the 20 cm rocks, as were barnacles and the tunicate, Molgula sp.

In contrast, the 20 cm rocks had less surface area, but more space between the rocks, allowing larger animals such as Crepidula spp. to accumulate and grow. The space also permitted a greater accumulation of hydroids and bryozoa as well as trapped debris and detritus, and this in turn often gave rise to more amphipods, especially the caprellids which cling to the erect branches of hydroids and elsewhere.

All relevant data for both size boxes, however, indicate that the biomass accumulation continued to rise during the study period and that a stabilized level has not yet been attained.

The results of analyses indicate that the detrital material was composed primarily of carbon and nitrogen and that the average carbon/nitrogen ratio was 7.5:1, which was relatively close to the estimates for phytoplankton

(Russell-Hunter, 1971) and zooplankton (Omari - in Parsons and Takahoshi, 1973). These data strongly suggest that live or recently living organisms such as phytoplankton and zooplankton have accumulated in the spaces within the gabions, presumably by a filtration process.

SCREENING PERFORMANCE

Laboratory Zooplankton Screening Tests

The results of the paired t-tests between control and experimental data from the flume are presented in Table 5. Nine different groupings of zooplankton were tested. No significant differences were observed between control and experimental conditions at the temperatures tested (1-16°C). It would appear that the groups of zooplankton studied were not capable of avoiding entrainment by a small scale porous dike under laboratory conditions at the temperature regime employed.

Field Zooplankton Screening Tests

Field zooplankton data were analyzed by grouping the zooplankton into 11 categories:

Acartia clausi (1.6%)

Acartia tonsa (0.9%)

Acartia spp. (3.4%)

Copepod nauplii (25.9%)

Total crustacea

Bivalve larvae (5.0%)

Gastropod larvae (0.3%)

Unknown rotifers (37.0%)

Unknown polychaetes (1.6%)

Unknown eggs (21.3%)

Total zooplankton

TABLE 5. RESULTS OF PAIRED T-TESTS FOR ZOOPLANKTON FLUME TESTS

Species	Source of Variation	Degrees of Freedom	Mean	Standard Deviation	Standard Error	T-Value
Acartia clausi	Control	8	0.17	0.13	0.04	-0.30 n.s.
	Experiment	8	019	0.19	0.06	
Acartia spp.	Control	9	0.25	0.21	0.07	-1.06 n.s.
	Experiment	9	0.31	0.26	0.08	
Copepod nauplii	Control	10	0.18	0.13	0.04	-1.62 n.s.
	Experiment	10	0.26	0.17	0.05	
Total crustacea	Control	10	0.17	0.12	0.04	-1.13 n.s.
	Experiment	10	0.23	0.15	0.04	
Bivalve larvae	Control	9	0.12	0.11	0.03	-1.22 n.s.
	Experiment	9	0.20	0.16	0.05	
Unknown rotifers	Control	7	0.04	0.05	0.02	-0.89 n.s.
	Experiment	7	0.07	0.07	0.02	
Unk. polychaetes	Control	10	0.07	0.08	0.02	-1.35 n.s.
	Experiment	10	0.13	0.15	0.05	
Unknown eggs	Control	9	0.25	0.23	0.07	0.56 n.s.
	Experiment	9	0.22	0.16	0.05	
Total zooplankton	Control	10	0.16	0.11	0.03	-1.41 n.s.
	Experiment	10	0.22	0.16	0.05	

n.s. = not significant.

Statistical analyses were performed to examine the distribution of zooplankton within the dike. The initial analysis was a paired t-test (Sokal and Rohlf, 1969) to test for population homogenity at the upstream face of the dike (Station 7.5A and 20A) (Figure 1).

The data sets were then subjected to a three-way factorial analysis of variance (ANOVA) (Sokal and Rohlf, 1969). The three factors were time (date of sampling), channel (7.5 and 20 cm) and sampling locations (A, B and C). For the purposes of this evaluation, the factors channels and sampling locations, and the channels-sampling locations interaction were tested.

The significance test for channels indicated whether the mean of all the samples taken in the 7.5 cm channel differed from the mean of all samples taken in the 20 cm channel. The significance test for sampling locations (A, B, C) would indicate whether the mean of the channels for the upstream sampling location would differ from the mean of the channels for the within-dike sampling location and/or from the mean of the channels for the downstream sampling locations. Finally, the significance test for the channels-sampling locations interactions would indicate whether one channel (i.e., rock size) yields different results from the other in terms of the zooplankton population.

A four-way factorial ANOVA (Sokal and Rohlf, 1969) was used to test for differences between the day and night populations, the fourth factor in the test being light.

As seen in Figure 1, the 20 cm channel has one more thickness of gabions than the 7.5 cm channel, made necessary by the hydraulic requirements of the design. This difference made it impossible to use the results of the ANOVA to establish whether the 7.5 or 20 cm channel has the greater screening ability. Therefore, to measure the differences between the channels at Station 20B and 7.5B), a paired t-test was performed on all of the samples collected in the gabions slots where symmetry existed.

The results of the paired t-test for the intake samples of the 7.5 and 20 cm channels are given in Table 6. In all cases, there were no statistically significant differences between the populations upstream of the 7.5 and 20 cm channels, indicating that both intake samples were taken from the same population of zooplankton.

The results of the three-way ANOVA analyses are given in Table 7. The channels assessment was used to test for population differences between the 7.5 and 20 cm channels. The population in each channel was defined as the mean of the three composite samples taken in that channel on any sampling date. As can be seen from Table 7, there were no population differences for any of the categories of zooplankton attributed to the channels (20 cm or 7.5 cm).

In analyzing for population differences between sampling locations (e.g., mean of 7.5A and 20A vs. mean of 7.5B and 20B, etc.). Table 7 shows that highly significant differences were found in all 11 categories of zooplankton.

The zooplankton population, except for gastropod larvae, was largest at the upstream sampling location on 67% or more of the sampling dates. For the holoplankton, except for rotifers, the population at the upstream sampling location was the largest on more than 75% of the sampling dates. For the meroplankton, the upstream population was largest on more than 60% of the sampling dates. If the data from January, February and March are not included in the above computation, the number of occasions when the upstream population was larger increases.

Figures 13 and 14 are plots of the density of Acartia clausi and total zooplankton taken from the upstream (A) and downstream (C) locations. As shown by the three-way ANOVA, the location (upstream or downstream) is a considerable source of variance.

These results indicate that the density of zooplankton is reduced by passing through stones.

TABLE 6. T VALUES FOR UPSTREAM FIELD ZOOPLANKTON SAMPLES

Species	Station	Degrees of Freedom	Mean+	Standard Deviation	Standard Error	T-Value
Acartia clausi	7.5A	67	2.73	1.06	0.13	0.46 n.s.
	20A	67	2.67	1.22	0.15	
Acartia tonsa	7.5A	70	2.19	1.28	0.15	-0.26 n.s.
	20A	70	2.22	1.25	0.15	
Acartia spp.	7.5A	89	3.41	0.55	0.06	0.41 n.s.
	20A	89	3.39	0.60	0.06	
Copepod nauplii	7.5A	89	4.43	0.43	0.05	1.53 n.s.
	20A	89	4.39	0.41	0.04	
Total crustacea	7.5A	89	4.57	0.42	0.04	1.49 n.s.
	20A	89	4.54	0.42	0.04	
Bivalve larvae	7.5A	76	2.66	1.50	0.17	-0.86 n.s.
	20A	76	2.75	1.49	0.17	
Gastropod larvae	7.5A	79	1.70	1.20	0.13	1.01 n.s.
	20A	79	1.56	1.22	0.14	
Unknown rotifers	7.5A	89	3.38	1.34	0.14	0.83 n.s.
	20A	89	3.34	1.44	0.15	
Unknown polychaetes	7.5A	89	2.72	1.00	0.11	0.27 n.s.
	20A	89	2.70	1.01	0.11	
Unknown eggs	7.5A	89	4.15	0.62	0.06	0.12 n.s.
	20A	89	4.15	0.58	0.06	
Total zooplankton	7.5A	89	4.93	0.51	0.05	0.14 n.s.
	20A	89	4.93	0.49	0.05	

+These values are the common logarithms of the mean.

n.s. = not significant.

TABLE 7. F RATIOS FOR ZOOPLANKTON THREE-WAY ANOVA

Source of Variation	Acartia clausi	Acartia tonsa	Acartia spp.	Copepod nauplii	Crustacea
Channel	1.91	3.45	0.17	0.63	0.96
Location	56.30[a]	46.12[a]	128.83[a]	126.44[a]	136.95[a]
Channel x Location	2.73	1.67	3.38	7.73	7.67

Source of Variation	Bivalve larvae	Gastropod larvae	Rotifers	Polychaetes	Eggs	Total Zooplankton
Channel	0.99	0.10	0.53	0.73	0.00	1.04
Location	47.63[a]	6.87[b]	24.78[a]	32.75[a]	54.52[a]	109.87[a]
Channel x Location	2.07	1.97	2.36	2.50	0.64	6.28[b]

a very highly significant $p < 0.001$
b highly significant $p < 0.01$
c significant $p < 0.05$

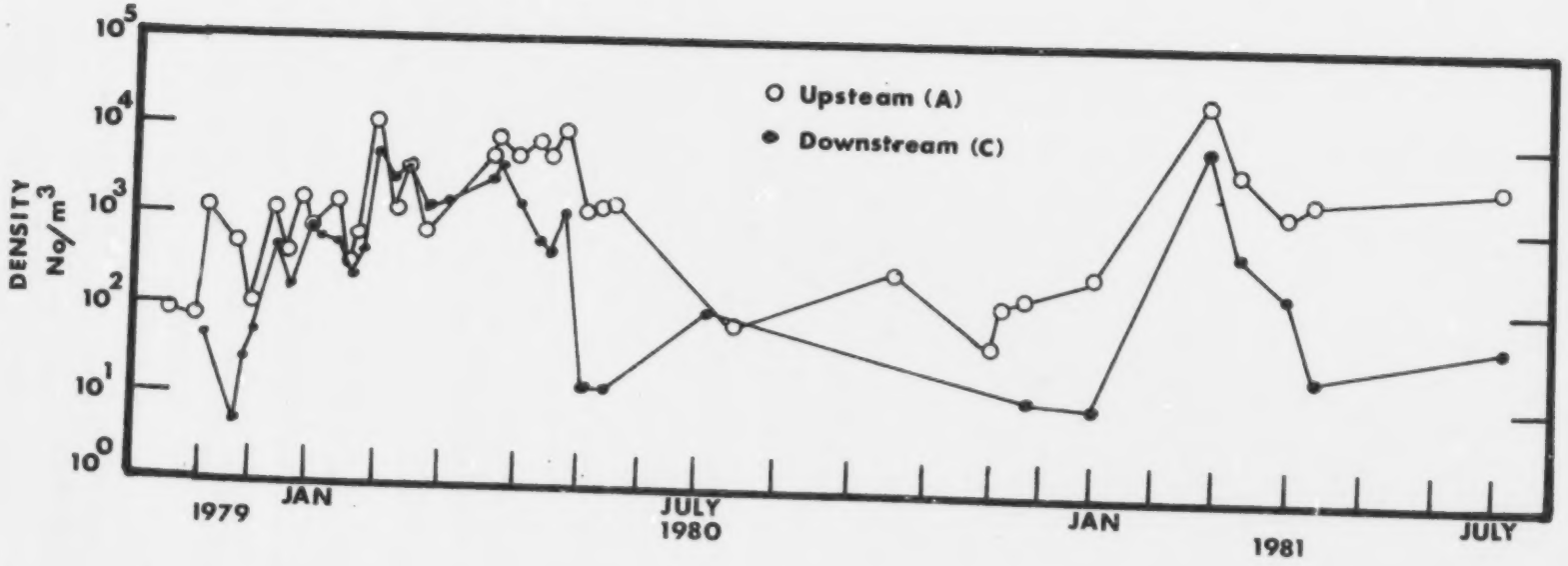

Figure 13. Acartia clausi density stations 20A and 20C.

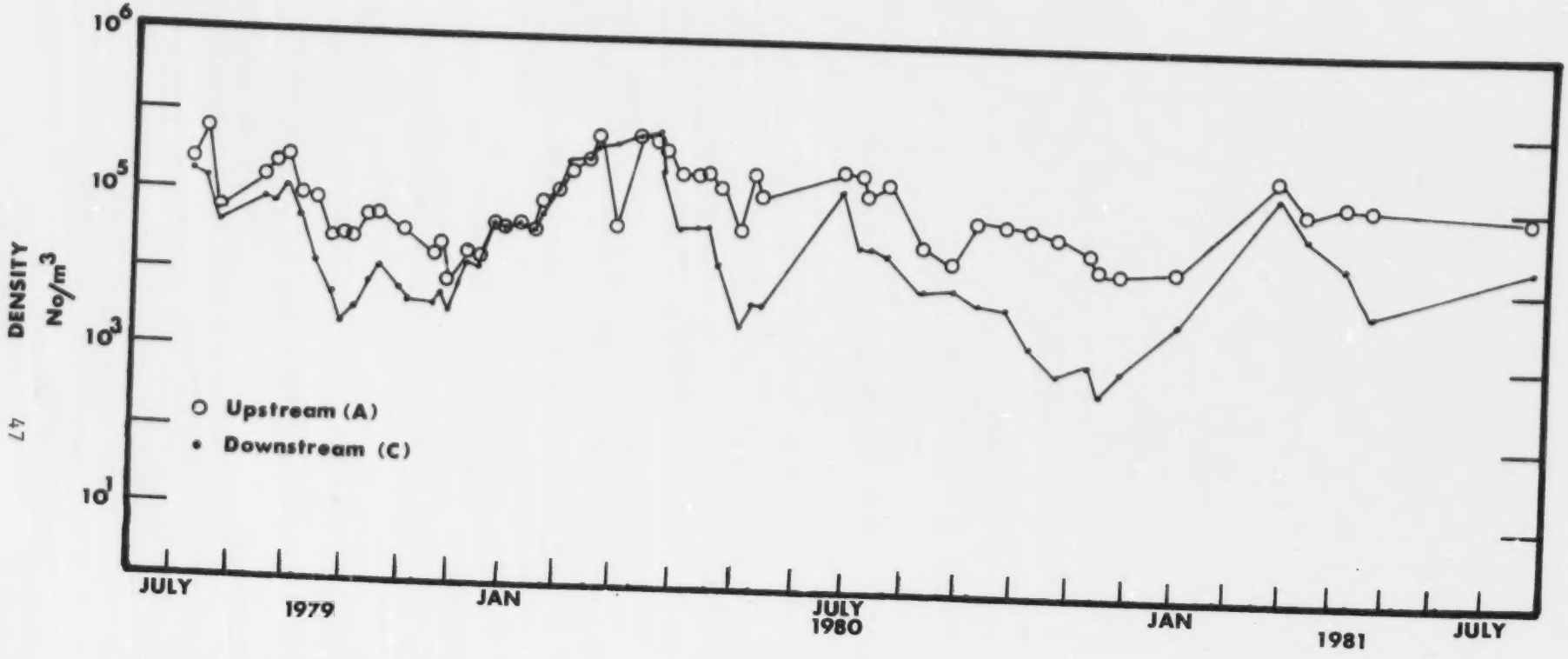

Figure 14. Zooplankton density stations 20A and 20C.

The results of the four-way factorial ANOVA for the day-night sampling dates are presented in Table 8. There were no significant differences between daytime and nighttime zooplankton populations and there were no significant differences between the zooplankton populations in each channel. The population differences between sampling locations was highly significant ($p < 0.01$) for unknown rotifers and unknown polychaetes and very highly significant ($p < 0.001$) for the other nine categories. These results are the same as were found for sampling locations in the three-way ANOVA.

The results of the paired t-test for comparing within-dike populations (Locations 7.5B and 20B) are given in Table 9. Significant ($p < 0.05$) differences were found for Acartia tonsa, Acartia spp., copepod nauplii and total crustacea, and highly significant ($p < 0.01$) differences for A. clausi and total zooplankton. In all cases, whether significant or not, the density of zooplankton in the water after passing through 0.9 meters of gabion was reduced by a greater amount by the 7.5 cm stones than by the 20 cm stones.

All these observations suggest that both the 7.5 cm stones and 20 cm stones reduce the density of zooplankton and the 7.5 cm stones have a greater effect per unit of flow path length.

Predation of entrained planktonic populations by the fouling community could contribute to these observed differences in upstream vs. downstream zooplankton populations. Those groups of animals found in the dike which were considered to be predators were the anthozoa, polychaeta and cirripedia. One way to estimate the effect of predation on the zooplankton was to see if the predator population within the dike decreased during the cold weather months when the zooplankton density was not reduced passing through the stones.

To analyze this hypothesis, a Friedman's test was employed to test the seasonal changes in abundance of the predators for the period starting in December 1979 and running to July 1981. The data indicated there was a

TABLE 8. F RATIOS FOR ZOOPLANKTON FOUR-WAY ANOVA

Source of Variation	Acartia clausi	Acartia tonsa	Acartia spp.	Copepod nauplii	Crustacea	Bivalve larvae
Day/Night	0.05	2.31	2.89	1.47	1.75	0.52
Channel	3.10	1.44	0.13	0.11	0.24	0.96
Location	25.19[a]	13.91[a]	34.08[a]	36.53[a]	38.45[a]	15.48[a]
Day/Night x Channel	1.16	0.63	1.41	0.02	0.28	0.00
Day/Night x Location	1.09	2.93	2.61	2.45	1.27	2.60
Channel x Location	1.55	0.33	0.84	1.02	1.42	0.12
Day/Night x Channel vs. Location	1.38	6.57[b]	1.41	0.82	0.16	0.08

Source of Variation	Gastropod larvae	Rotifers	Polychaetes	Eggs	Total Zooplankton
Day/Night	0.94	1.95	2.73	0.98	1.65
Channel	0.02	0.36	0.93	0.11	0.75
Location	1.36	8.05[b]	7.73[b]	20.83[a]	31.30[a]
Day/Night x Channel	0.08	3.45	0.38	2.55	0.77
Day/Night x Location	0.37	0.95	1.25	0.23	1.23
Channel x Location	3.24	0.99	1.35	0.51	1.87
Day/Night x Channel x Location	0.86	0.01	1.42	0.90	0.43

a very highly significant $p < 0.001$

b highly significant $p < 0.01$

TABLE 9. T VALUES FOR WITHIN DIKE ZOOPLANKTON DENSITY

Species	Source of Variation	Degrees of Freedom	Mean+	Standard Deviation	Standard Error	T-Value
Acartia clausi	7.5B	67	2.07	1.38	0.17	-3.05**
	20B	67	2.34	1.16	0.14	
Acartia tonsa	7.5B	70	1.32	1.20	0.14	-2.34*
	20B	70	1.61	1.21	0.14	
Acartia spp.	7.5B	89	2.60	0.96	0.10	-2.49*
	20B	89	2.76	0.96	0.10	
Copepod nauplii	7.5B	89	3.96	0.63	0.07	-2.02*
	20B	89	4.02	0.61	0.06	
Total crustacea	7.5B	89	4.13	0.60	0.06	-2.10*
	20B	89	4.18	0.59	0.06	
Bivalve larvae	7.5B	76	2.22	1.39	0.16	-1.88 n.s.
	20B	76	2.40	1.47	0.17	
Gastropod larvae	7.5B	79	1.40	1.07	0.12	-1.31 n.s.
	20B	79	1.58	1.17	0.13	
Unknown rotifers	7.5B	89	2.98	1.58	0.17	-1.95 n.s.
	20B	89	3.14	1.49	0.16	
Unknown polychaetes	7.5B	89	2.29	0.96	0.10	-1.06 n.s.
	20B	89	2.40	1.00	0.11	
Unknown eggs	7.5B	89	3.97	0.70	0.07	-0.75 n.s.
	20B	89	3.99	0.74	0.08	
Total zooplankton	7.5B	89	4.59	0.70	0.07	-3.18**
	20B	89	4.66	0.70	0.07	

+These values are the common logarithms of the mean.

n.s. = not significant.

*$p < 0.05$, significant.

**$p < 0.01$, highly significant.

seasonal variation in predator abundance and that there was a general accumulation of predators with time. The predator population within the dike in December 1979 was only a small fraction of the population measured in early March 1981 when the temperature was representative of that found in the coldest months (1.9 to 5 C), and yet the reduction of zooplankton numbers was relatively similar for both months. This implies that the standing crop of predators had little effect on the zooplankton density. However, predation may be a function of temperature with predators feeding more actively at higher temperatures than at lower temperatures.

Reduction in the density of zooplankton could also be due to filtration.

Fouling box data showed that there was an accumulation of material within the dike which increased in mass and volume with time.

Sediment was sampled from the upstream and downstream face of the gabions to determine whether the non-attached material that settled out was inorganic or organic. Microscopic observation of the material revealed large amounts of phytoplankton, zooplankton and partially decomposed crustaceans.

As previously stated, chemical analysis of this material showed it to be primarily carbon and nitrogen (Table 10) (C:N = 7.5:1) confirming an organic origin.

Table 10. Sediment Analysis

		Carbon			Nitrogen			
Sample	Weight (g)	% Carbon	Weight Carbon (g)	G. Atoms Carbon	% Nitrogen	Weight Nitrogen (g)	G. Atoms Nitrogen	Ratio (C/N)
7.5A	49	14.20	6.96	0.58	2.65	1.30	0.09	6.44
20A	48	20.80	9.98	0.83	4.13	1.98	0.14	5.93
7.5C	49	9.96	4.88	0.41	1.22	0.60	0.04	10.25
20C	50	12.60	6.30	0.53	1.94	0.97	0.07	7.57
							$\bar{x}$	7.54

Laboratory Fish Screening Tests

Results of the laboratory observational studies conducted with larval juvenile and adult fish are presented for each species tested.

Larval Atlantic menhaden (Brevoortia tyrannus), threespine sticklebacks (Gasterosteus aculeatus), northern pipefish (Syngnathus fuscus), windowpane (Scophthalmus aquosus) and winter flounder (Pseudopleuronectes americanus), were reared in the laboratory and observed at various intervals during their development. Menhaden and windowpane were reared from eggs. Larvae of the stickleback and pipefish were obtained by holding adults in the laboratory, and winter flounder eggs were obtained from gravid females and artificially spawned in the laboratory. Juvenile and adult fish were collected by seine and held in the laboratory for testing.

Larval fish observations are summarized below:

Atlantic menhaden, age 14-15 days, total length 10-12 mm

Six larvae were individually observed in this size class at a water flow of 2 cm/sec. In each case, within approximately five minutes of release, two were entrained through the gabion and the remaining four were impinged on screen B. Although all six larvae swam continuously, they were unable to make upstream progress unless, as in one case, they entered the surface boundary layer. Of the two entrained larvae, one made no effort to avoid drifting into the rocks; the other displayed an increase in swimming speed (although no forward motion resulted) as the current accelerated at the face of the gabion; both entered tail first while swimming into the current.

Atlantic menhaden, age 22-23 days, total length 13-15 mm

Ten larvae in this size class were observed at 2 cm/sec. The larger individuals displayed considerable improvement in swimming ability compared with the 10-12 mm larvae. Three larvae were entrained, four were impinged on screen B and three successfully avoided the gabion flow. Among the larvae that were entrained or successfully avoided entrainment, each one responded

to the current entering the rocks by quickly orienting 90° to the face of the rock, i.e., heading into the current, and increasing their swimming speed. All three of the larvae that successfully avoided entrainment did so with a burst of swimming which carried them well beyond the influence of the gabion.

Atlantic menhaden age 36-37 days, total length 15-20 mm

Seven larvae in this size class observed at 2 cm/sec. appeared to have little difficulty swimming against the 3.5 cm/sec. current in the front section of the flume. Each of the larvae approached the gabion at least once during the one-hour observation periods. In most cases, the larvae darted away from the gabion after sensing the accelerated flow rate within the rock pores. One of the larvae drifted toward the gabion on four separate occasions, and in each case it darted away. One larva did not dart away on its first encounter with the gabion and was entrained with no apparent change in swimming speed. Interestingly, two larvae among those which successfully avoided entrainment one or two times approached the gabion at a subsequent point and allowed themselves to be entrained, making no effort to escape at that point.

Atlantic menhaden, age 43-45 days, total length 20-25 mm

Menhaden in this size class were difficult to work with since they reacted badly to being transferred from the rearing tanks to the flume. In several cases, larvae would drift passively after release, sometimes sinking to the bottom or swimming about in circles. Seven larvae among those tested appeared to behave "normally" after a period of acclimation in the flume and were observed at 3 cm/sec. All of the larvae appeared capable of swimming upstream against the 8.5 cm/sec. flow in the forward section of the flume. Two of the seven fish swam throughout the chamber for one hour displaying no interest in the rocks; one swam past the gabion on several occasions

within 25 mm of the face, but did not display any reaction to the current entering the rocks. Three of the larvae swam around the flume for several minutes, then approached the gabion where they were entrained head first, making no apparent effort to escape. The two remaining larvae were impinged on screen B, although one did successfully swim away from the gabion after being drawn to it by the current prior to being impinged.

Atlantic menhaden, age 55-56 days, total length 25-30 mm

A group of eight menhaden were observed for one hour at 2 cm/sec., followed by one hour at 3 cm/sec. Early in the observation period at 2 cm/sec. one fish swam into the gabion head first and passed through to the downstream side. On four subsequent occasions at the lower velocity, a fish was drawn toward the gabion, but in each case, darted away before being entrained. With the current at 3 cm/sec., the fish showed no interest in the gabion and spent most of the hour swimming into the current near screen A. During these observation periods, four of the eight fish (two during each period) swam downstream to screen B and, after being briefly impinged, darted along the screen and became trapped behind the side panel where they were lost.

Threespine stickleback, age 7 days, total length 5-6 mm

Six larvae at this size were unable to avoid the gabion at a velocity of 2 cm/sec; the velocity across the front chamber was approximately 3 cm/sec. Although some larvae were able to swim upstream in areas where the current was about 2 cm/sec, they were clearly unable to escape the gabion flow. (Pore velocities were around 4 cm/sec., so many could not be measured with a flow meter.) Before being entrained, each larva made an attempt to escape by darting forward 1-2 cm into the current, but was then drawn into the rocks tail first.

After two larvae were entrained at this velocity, the remaining four found an area of reduced velocity at the base of discharge screen A. At

That point, the velocity was increased to 3 cm/sec. downstream of the gabion. Three of the remaining larvae were entrained within 15 minutes shortly after rising off the bottom.

Threespine stickleback, age 12-19 days, total length 6-7 mm

Swimming ability of larvae in this size range was noticeably improved. If the current began to carry them downstream, they would frequently drop to the bottom boundary layer where the flow was reduced and were, therefore, better able to hold position or, in some cases, move upstream. Although one of four larvae tested was entrained at 3 cm/sec., one larva of this size did display the ability to escape the flow at the face of the gabion when set at 2 cm/sec.

Threespine stickleback, age 32 days, total length 10 mm

Nine larvae were tested at 4.0-4.5 cm/sec. Seven of them (78%) were entrained within 60 minutes, although in each case, the larva attempted to swim away from the gabion as it was entrained. On two occasions, larvae were drawn toward the gabion, but were successful in escaping from a pore where the current was 8.5 cm/sec.

A single 10 mm larva was observed at 3 cm/sec. This larva was able to dart upstream at this velcoty and did so several times. Periods of swimming were occasionally replaced, however, by periods of passive drifting. During one of these periods, the larva drifted into and through the gabion, making no apparent effort to escape the rocks.

Between 10 and 15 mm TL larvae developed sufficiently to avoid entrainment at about 3 cm/sec. as described below for juveniles.

Northern pipefish, age 2 days, total length 12-15 mm

Pipefish at this size were relatively inactive in the rearing tanks. They remained primarily near the surface, but would occasionally drift around passively if caught in currents created by an airstone. Among the larvae

larvae observed at this size (n = 16 at 2 cm/sec.), 4 passed through the gabion and 12 were impinged on downstream screen B and were unable to swim off. Three of the four entrained larvae drifted passively into the gabion; one did display an increase in swimming speed just before entering the rocks, but failed to slow its rate of drift.

Northern pipefish, age 17 days, total length 15-20 mm

Two larvae were observed in this size class (velocity = 2 cm/sec). Although both larvae were entrained, swimming ability increased considerably over the 2-day old larvae. In both cases, the larvae attempted to swim away from the gabion current before being entrained, and in two encounters, the larvae escaped from one rock pore before being entrained by another.

Windowpane, age 28 days, total length 5-6 mm

Windowpane larvae were reared to 28 days post-hatching, just prior to metamorphosis (5-6 mm TL) and observed at 2 and 3 cm/sec. These larvae appeared to be relatively passive in rearing containers, drifting or weakly swimming at the surface. In the flume, at both velocities, larvae spent much of the observation period drifting with an occasional darting motion in what appeared to be random directions. In each case, they were either entrained or drifted up against the downstream screen B. In one trial at 2 cm/sec., a larva was able to swim ahead of the gabion until the cross current carried it downstream past the gabion. In another trial at 3 cm/sec., a larva began to swim into the current just prior to entrainment, made some headway, but then stopped swimming and was passively entrained.

Winter flounder, age 1-7 days, total length 3 mm

Larvae at this age and size were passive drifters. They either remained at the surface where the water was quite stationary (current in forward section of the flume was set at approximately 1 cm/sec.), or alternated periods of passive sinking with periods of swimming back to the surface. When drifting into the gabion, no change in behavior was apparent.

Winter flounder, age 22 days, total length 3-4 mm

Larvae at this size displayed an improvement in swimming abilities. They were capable of some upstream movement in a current of about 3 cm/sec. However, they still spent time passively drifting and, if they happened to be near the gabion, were entrained.

Winter flounder, age 26 days, total length 4-6 mm

Observations were made on these larvae with the direction of flow reversed, i.e., water entered the flume at C (Figure 2) and exited at B. No water flowed past position A. Larvae released at position C and observed in a current of about 2 cm/sec. attempted to swim upstream, but were only able to slow their downstream rate of drift. Larvae were able to avoid entrainment only by remaining on the bottom, which they frequently did for long periods of time (up to 35 minutes in one case). When they rose off the bottom, each larva tested was entrained. Larvae observed at 0.5 cm/sec. behaved in a similar manner and were also entrained.

Winter flounder, age 38-40 days, total length 6.5-9 mm

Larvae at this age were beginning to metamorphose. With the flume in the reverse setting and a current of 2 cm/sec., larvae were still unable to swim upstream and were entrained.

Among 11 larvae observed in the normal direction of flow at velocities of 2 to 3 cm/sec., five were entrained through the gabion and six were impinged on the downstream screen B. Although, in some cases, these larvae displayed the ability to dart off the downstream screen and move away from the gabion when no closer than three or four cm, they were relatively ineffective swimmers and made no apparent effort to escape from the rocks once entrainment began.

Winter flounder, age 54 days, total length 10-12 mm

Winter flounder at this age and size had all transformed and settled to the bottom where they were quite inactive. One juvenile at this size placed in the flume did not move during a three-hour observation period. During this period, velocities were varied from 3 to 9 cm/sec. with no observable change in behavior.

Juvenile and adult fish observations are summarized below:

Pollock (Pollachius virens)

Twelve juvenile pollock were observed for three hours at a velocity of 3 cm/sec. During this period, they displayed little attraction to the rocks. Each time an individual passed close enough to the gabion to sense the flow through the rocks, it turned to head into the current entering the gabion (i.e., the fish assumed a position approximately 90° to the gabion entrance, head facing outward), increased its swimming speed and moved off, generally within one to three seconds. During the three-hour observation period, none of the fish entered the gabion.

Sheepshead Minnow (Cyprinodon variegatus)

Eleven sheepshead minnows were observed for approximately two hours at 3 cm/sec., followed by one hour at 2.5 cm/sec. This experiment was duplicated with the same fish nine days later; the observation period at 2.5 cm/sec. was increased to two hours during the second session. At 3 cm/sec., the fish displayed little attraction to the gabion. Groups of fish occasionally swam past the gabion within 10 cm of the rock face without any visible indication that they sensed the flow vector into the rocks. During the four observation hours at this velocity, one individual did enter the face of the gabion head first. This fish immediately turned 180° within the face of the gabion, paused for about one second, and swam out and away from the rocks.

When the velocity was reduced to approximately 2.5 cm/sec. downstream of the gabion, attraction to the rocks (side panels and gabion) appeared to increase. Fish spent more time exploring the rocks and several groups entered the gabion. During the first session, four fish (36%) swam into and passed through the gabion within 15 minutes of the current change. During the second session, three (27%) passed through within 10 minutes of the velocity reduction. It was interesting to note that in both experiments no additional fish entered or passed through the gabion after the initial 10 or 15-minute period.

Mummichog (Fundulus heteroclitus)

In some cases, the mummichog displayed a great attraction to the gabion while in others they did not. For example, in two sessions at 2.5 and 3 cm/sec. involving 28 and 35 individuals, respectively, both in the 20 to 50 mm TL size range, an average of 34% of the fish entered and passed through the gabion. In a similar test with 23 somewhat larger fish (40-110 mm TL), 8 (35%) passed through the gabion. In these tests, making accurate counts was complicated by the fact that in many instances fish would re-enter the gabion from downstream and pass back to the forward chamber, while others would enter the gabion and remain there for some time so that there appeared to a nearly constant exchange of fish. At 6 cm/sec., fish would frequently enter the gabion, but in most cases, they would quickly dart out. For example, in one 45-minute period at 6 cm/sec. with 75 mummichogs (30-50 mm), 13 times fish entered the face of the gabion and immediately darted out again. None of the fish passed through to the downstream side in this particular study.

Interestingly, in some observations periods involving different groups of mummichogs under 50 mm, the amount of interest displayed toward the gabion was considerably less. For example, in three separate tests with 20 fish

each at 2 cm/sec. for 1 to 2 hours, in only two instances did fish enter the face of the gabion and in both cases they left the rocks without passing downstream. Similar results were obtained in one test at 3 cm/sec. and another at 6 cm/sec.

Larger mummichogs (70-100 mm) rarely entered the gabion, although they appeared to be attracted to it. Their larger size relative to the size of pores in the gabion may have been an important factor. At 3 cm/sec., only one fish of 21 observed for a total of 13 hours in two separate tests passed through the gabion. On one occasion during these observations, two fish quickly darted in and out of the face of the gabion. At 6 cm/sec. fish (n = 12 observed for 30 minutes) did not pass through the gabion, but two did enter the face and quickly exit again. One fish did so head first, the other drifted in tail first.

Two 24-hour experiments were conducted with 20 to 30 small mummichogs (25-35 mm TL) at 3 cm/sec. In the first test, 13% of the fish passed through the gabion and in the second 15% passed through. In both tests, all fish passed through the gabion during the first three to five hours. In these particular periods, once the fish passed through, they did not return upstream although in one case, fish did enter the downstream side of the gabion for a period of time.

Atlantic silverside (Menidia menidia)

Atlantic silversides were unusual among the fishes observed in that they avoided the rocks of the gabion and side panels in nearly all situations. Test velocities ranged from 1.5 to 12 cm/sec. In most cases, these fish headed into the current and maintained position at the discharge screen (A in Figure 2). On one occasion, a screen was inserted across the flume from the right-hand edge of the gabion to the viewing window in an effort to force silversides to swim near the gabion. Flow was varied from 1.5 to 12 cm/sec;

throughout this session, the fish swam with their snouts almost in contact with the new screen as far from the gabion as possible.

In a combined total of 14 hours of observation involving 58 fish, in only one case did a silverside approach the gabion. This occurred at a flow rate of 2 cm/sec., and the fish, unlike all other silversides observed, swam up to the face of the gabion, paused for one second and swam in head first. The fish did not appear downstream and presumably was trapped inside.

Fourspine stickleback (Apeltes quadracus)

Adult fourspine sticklebacks were observed at 2.5, 3, 6 and 9 cm/sec. Observations were made in duplicate at each velocity for a minimum of 30 minutes (one 60-minute session was conducted at 9 cm/sec.)

The fourspine stickleback ranged among those species which showed no interest in the gabion. Individuals would frequently swim past the gabion entrance, but no response to the rocks or flow was apparent. On four occasions, during a test at 6 cm/sec. a fish approached close enough to the gabion to be drawn toward it by the current. In each case when the fish sensed the current into the rocks, it darted out of the area. In some sessions, fourspine sticklebacks behaved like silversides in that they remained at the discharge screen.

Threespine stickleback

Unlike the fourspine, threespine sticklebacks displayed some attraction to the rocks. At test velocities between 3 and 9 cm/sec. invovling 15-20 adult fish per test, individuals would occasionally approach the gabion, but in each case, they would swim away when the current began to pull them into the rocks. None of the fish tested were drawn or swam through to the downstream side of the gabion. On one occasion, fish were observed at 20 cm/sec. (n = 17). At this velocity, they were still able to cross in front of the gabion without being drawn in.

Observations were also made on juvenile threespine sticklebacks ranging in size from 15 to 30 mm TL. At 2.5 and 3 cm/sec., no entrainment occurred through the gabion. In approximately three hours of observation involving 45 fish, several individuals did swim into the gabion; however, these juveniles immediately darted out again, appearing to do so when they sensed the current acceleration through the rocks. During these sessions, fish frequently swam by the gabion while milling about the chamber. When they began to be drawn toward the rocks, they would turn into the flow (at a right angle to the gabion face) and move either straight off or laterally until they were out of the flow entering the rocks. At 6 and 7 cm/sec., some juveniles began to be entrained. In 30 minutes of observation at each velocity, a total of 4 fish (n = 40) were entrained. Three were drawn in tail first while swimming past the gabion, the fourth while searching the face of the gabion. Several other juveniles did successfully pass the gabion as described at 3 cm/sec., and one was almost drawn in, but managed to escape.

Northern pipefish

Adult northern pipefish were observed in groups of 20 to 30 fish at velocities of 2, 3 and 6 cm/sec. They displayed relatively little attraction to the rocks, although one or two fish did rest among the rocks of the side panels for long periods of time (e.g., 30 minutes). On one or two occasions at each velocity a fish approached the face of the gabion but, when the current began to draw it toward the rocks, each fish swam away. At one point during observations at 3 cm/sec., a pipefish was drawn into the face of the gabion, but it quickly darted out and moved away.

Scup (Stenotomus chrysops)

Juvenile scup approximately 40-70 mm TL (n = 30) were observed at 2, 3 and 6 cm/sec. for approximately one hour per velocity. Larger scup, approximately 80-100 TL (n = 4) were also observed at 3, 6 and 12 cm/sec. for about

30 minutes per velocity. These fish displayed no attraction to the rocks of either the side panels or gabion. The smaller size group never approached the rocks while the larger fish did so only occasionally. When the larger fish did pass near enough to sense the flow entering the gabion, they turned into the current, occasionally swam against the gabion current for several minutes and then moved off.

Cunner (Tautogolabrus adspersus)

Ten juvenile cunner (35-60 mm TL) were observed consecutively at 3, 2 and 6 cm/sec. for one hour per velocity. These fish settled within the gravel spread on the bottom of the flume and were relatively inactive. During the three hours of observation, only one fish approached the gabion. It swam into the face of the gabion (flow - 3 cm/sec.), remained out of sight for several minutes, and then swam out and away from the gabion, rejoining the other fish scattered within the gravel.

Larger cunner (65-90 mm TL) were observed at 4 cm/sec. for 40 minutes followed by 7 cm/sec. for 30 minutes. No gravel was used on the bottom. At both velocities, these fish were strongly attracted to the gabion and side panels. On many occasions, one plunged into a pore in the gabion, but because of its relatively large size, was unable to fit. Some backed out and swam around for a period of time; others kept trying additional pores until they located one large enough to enter. Those that did not find space in the rocks settled on the bottom, usually near one of the rocks placed there or against the side panels. None of the fish passed through the gabion to the downstream side.

No change in behavior was apparent at the two velocities among the larger cunner. Among the smaller fish, activity appeared to decline at 6 cm/sec. when compared with 2 and 3 cm/sec.

Northern searobin (Prionotus carolinus)

Six northern searobins (3 = 50 mm TL, 3 = 100-125 mm TL) were observed

at 3 and 6 cm/sec. for 30 and 45-minute periods, respectively. These fish never approached the gabion or side panels during this test. When milling about the chamber, they remained away from the rocks so that they never entered the flow vector entering the gabion. They spent most of the observation period on the bottom heading into the primary current.

Winter flounder

Winter flounder juveniles (15-30 mm) were observed at velocities of 2 (n = 21, 2 hours) and 6 cm/sec. (n = 16, 4 hours). At both velocities, these fish were attracted to the gabion and the rocks of the side panels. Fish frequently came to rest under the rock overhang along the base of the side panels or at the base of the gabion. At 2 cm/sec., they were able to swim along the base of the gabion without being drawn toward the rocks, and none of the fish sawm into the face of the gabion. At 6 cm/sec. when fish swam past the gabion, they were frequently drawn toward the rocks by the stronger flow rates in the pores. In all encounters, but two, the fish darted away from the gabion when the current began to draw them in. Two fish which approached the gabion were unable to escape the flow and were drawn in tail first; both passed through to the downstream side.

Larger juveniles (50-100 mm, n = 11) were observed at 3 cm/sec. for about 6 hours. At this velocity, behavior was similar to that described for the smaller juveniles, and in this test, three fish did enter the gabion. However, these fish did not pass through the gabion to the downstream side, perhaps because of their larger size.

Although winter flounder in the 90-200 mm TL size range were too large to enter the gabion, observations were made to determine if they were attracted to the rocks. Six flounder were observed at 3 cm/sec. for over 5 hours. During this time, the fish were relatively inactive. Movement

wsa infrequent and over very short distances. They did not appear to be attracted to the rocks, although occasionally, one would come to rest at the base of the gabion.

In a subsequent experiment, these fish were observed for one hour each at 7, 8.5 and 9.5 cm/sec. No change in behavior was apparent at these higher velocities.

Results from the filtration capacity study using fouling tubes, flounder larvae and labrid eggs indicated that eggs and larvae passed more readily through the box containing clean stone than through the box containing fouled stone (Table 11). With the exception of stage I winter flounder larvae in the clean box, results were quite consistent within boxes, particularly the fouled box. These data suggest that larvae passively drifting into the porous dike can be physically filtered by the fouling material on the rocks. Approximately 60% of the eggs and larvae were filtered by the fouled stones.

In these tests, the largest (stage III) larvae were not filtered out more readily than the small larvae. At the field test facilities, the percent reduction was higher for these larvae. This difference could be interpreted in one of two ways: (1) the much shorter length of stone in the fouling box (0.6 m) versus the actual test structure (3.7 m) may make direct comparisons difficult; (2) stage III larvae actually avoided the field test facility.

One possible source of bias in the fouling box study is the fact that preserved eggs and larvae are negatively buoyant, while live labrid eggs are clearly positively buoyant. Live larval flounder do sink when they become inactive.

Field Fish Screening Tests

Field screening tests were conducted for fish eggs and larvae and adult and juvenile fish.

TABLE 11. ICHTHYOPLANTKON FILTRATION

Stage	Number Introduced	Number Recovered	% Filtered	Number Recovered After Flush	Total % Filtered
		Clean Stone			
P. americanus I	400	154	61.5	2	61.0
P. americanus II	600	511	14.8	7	13.7
P. americanus III	600	567	5.5	16	2.8
Eggs	600	427	28.8	41	22.0
		Fouled Stone			
P. americanus I	400	175	56.3	7	54.5
P. americanus II	600	219	63.5	41	56.7
P. americanus III	600	246	59.0	30	54.0
Eggs	600	222	63.0	26	58.7

Ichthyoplankton

Ichthyoplankton samples were analyzed for density differences. Only those categories which showed sufficient densities for analysis were presented. These categories were bay anchovy larvae, Atlantic silverside larvae, tautog larvae, cunner larvae, sand lance larvae, seaboard goby larvae, winter flounder larvae, total larvae, winter flounder eggs and total pelagic eggs. The percent differences in catch between upstream (A) and downstream (C) positions were plotted for each sampling period by species and channel in Figures 15 and 16 and Appendix Figures 1-5. The upstream densities were compared statistically with corresponding densities recorded at downstream positions within each sampling period using paired-sample t-tests (Sokal and Rohlf, 1969). Densities were log transformed (base e) before conducting the t-tests.

In most cases, significantly fewer larvae were taken downstream compared with upstream. Averaged over both channels and all sampling dates, the percent difference across the stone gabions ranged from 53.2% among anchovy larvae to 88.1% among larval tautog. Percent reduction values of 90% or more were not uncommon on individual sampling dates.

Among larval anchovy, cunner, tautog and winter flounder, percent reduction across the dike appeared to increase with time in both channels. Among anchovies and winter flounder, which were abundant over several weeks in both 1980 and 1981, the increase over time occurred both years.

Entrainment of winter flounder larvae was investigated in more detail by examining the percent reduction per developmental stage (Table 12). One point which is fairly clear from these data is that the largest or stage III flounder larvae displayed a greater decrease in numbers across the dike than the smaller stage I and II larvae. Among stage I and II, larval flounder percent reduction increased over time in both channels. This was more apparent in 1980 than in 1981, perhaps because flounder were abundant over a greater period of time in 1980.

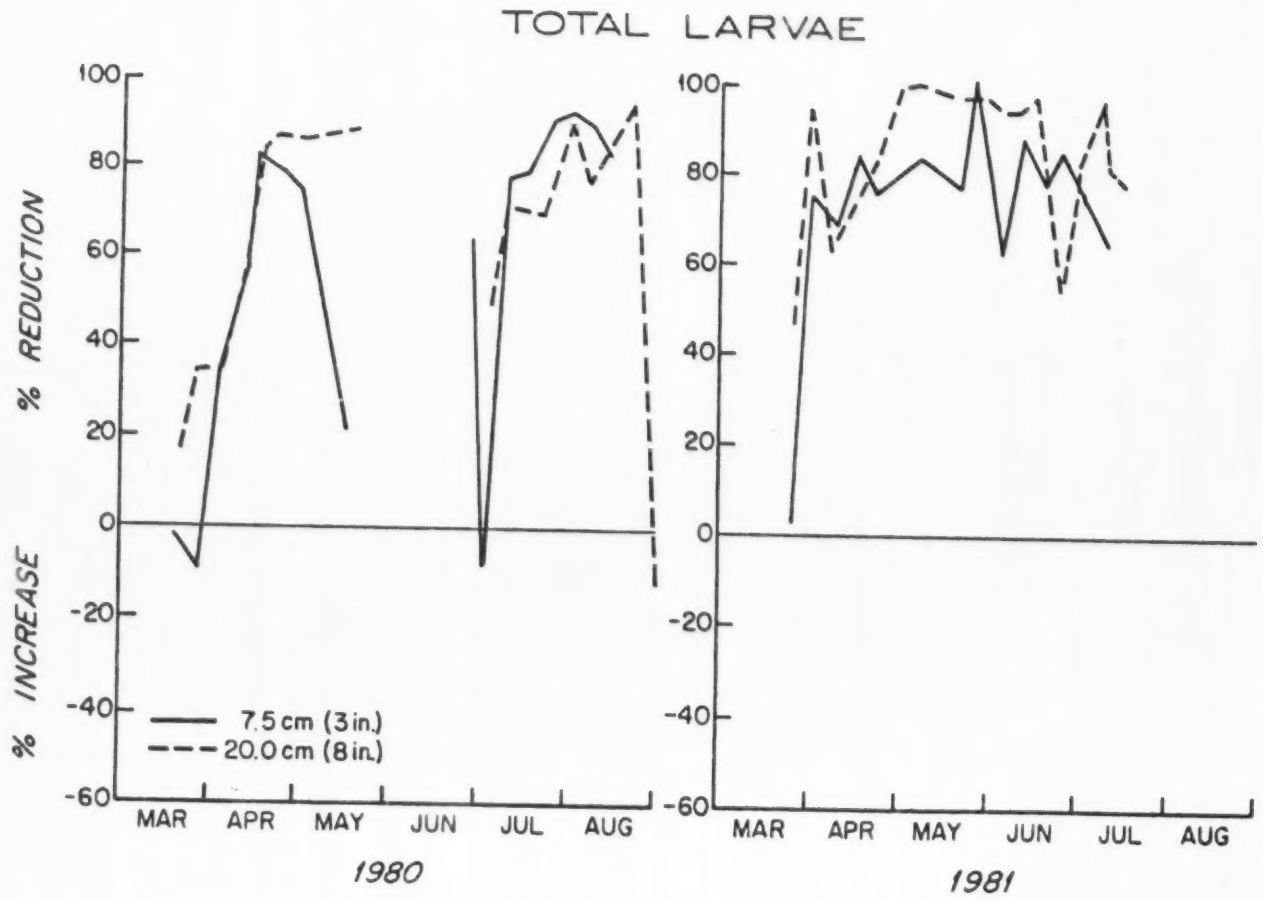

Figure 15. Percent difference in larval fish density between stations A and C.

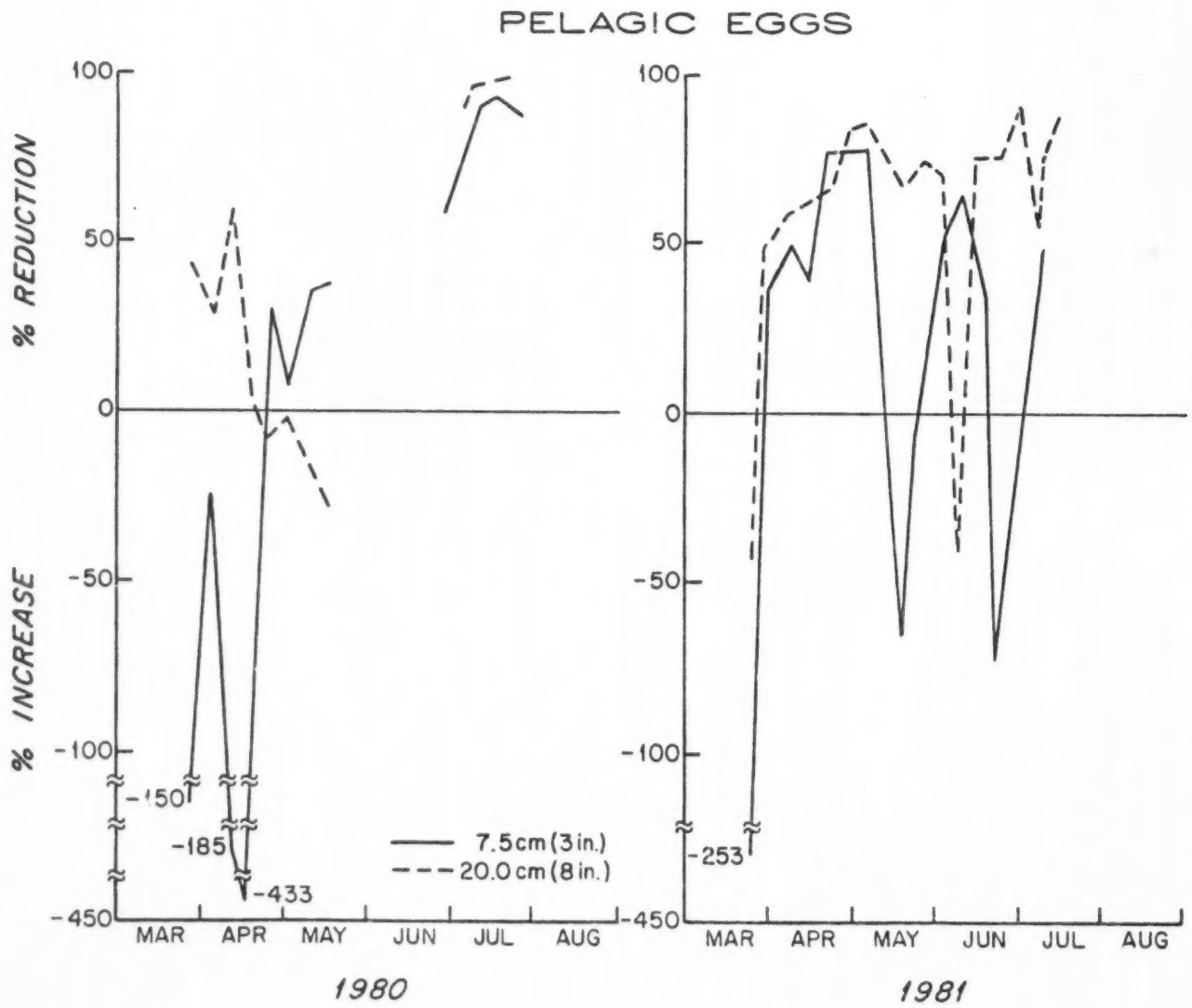

Figure 16. **Percent difference in pelagic egg density between stations A and C.**

TABLE 12. STAGED LARVAL WINTER FLOUNDER DENSITY

Date	Upstream			Downstream			% Difference			Number of pairs
Stage:	I	II	III	I	II	III	I	II	III	
				7.5-cm Channel						
1980										
March 19	262.7	-	-	279.9	-	-	-6.5	-	-	6
26	340.1	39.6	-	366.8	52.8	-	-7.8	-33.3	-	10
April 3	181.4	115.5	-	94.5	98.1	-	47.9	15.1	-	10
11	328.6	51.6	-	148.4	20.5	-	54.9	60.4	-	10
15	440.5	1369.9	276.7	66.0	263.4	20.1	85.0	80.8	92.8	10
24	-	28.2	12.9	-	7.1	0.7	-	74.7	95.0	10
30	-	6.5	11.3	-	1.9	2.6	-	70.0	77.1	6
1981										
March 24	210.1	207.4	-	195.0	166.5	-	7.2	19.7	-	4
Mar 31 Apr 1+	404.1	592.7	5.7	170.2	143.3	3.6	57.9	75.8	36.8	6
April 8+	21.7	136.8	16.8	35.9	52.0	5.3	-65.4	62.0	68.5	8
15+	3.2	20.5	58.2	0.6	2.6	6.9	81.3	87.3	88.1	9
21	-	-	5.0	-	-	1.3	-	-	74.0	5
				20-cm Channel						
1980										
March 20	350.3	-	-	270.5	-	-	22.8	-	-	6
25	351.3	25.9	-	223.7	12.5	-	36.3	51.9	-	10
April 4	2527.0	76.7	-	1640.1	66.2	-	35.1	13.7	-	10
10	840.9	83.1	-	406.5	27.3	-	51.7	67.2	-	10
17	42.4	289.7	408.7	5.4	68.3	37.5	87.3	76.4	90.8	10
22	-	39.5	95.8	-	6.8	10.4	-	82.8	89.2	10

(continued).

Table 12. (continued).

Date	Stage:	Upstream I	Upstream II	Upstream III	Downstream I	Downstream II	Downstream III	% Difference I	% Difference II	% Difference III	Number of pairs
1981											
March	25	118.9	87.5	-	69.5	45.5	-	41.5	48.0	-	6
	31	72.6	16.9	-	25.0	2.5	-	65.6	85.2	-	6
April	7	65.8	154.8	21.5	39.7	49.9	2.1	39.7	67.8	90.2	6
	22+	-	31.7	54.3	-	7.9	5.8	-	75.1	89.3	13
	29+	-	-	131.4	-	-	1.6	-	-	98.8	12

+day and night samples combined.

The data on staged larval flounder were of particular interest because they provided information on how the porous dike functioned in reducing entrainment among winter flounder and perhaps other species of larvae as well. The fact that the largest, stage III flounder passed through the dike less frequently may be attributed to two factors. The larger larvae may be more efficient swimmers and, therefore, better adapted for avoiding entrainment in water drawn through a porous dike or their larger size may cause them to be physically trapped within the dike at a greater frequency. Entrapment within the dike could be purely physical or caused by the activities of invertebrates living and feeding within the dike.

Since our flume studies have shown that little increase in size or swimming ability occurs within larval flounder stages I and II, the observed steady increase in percentage reduction suggests that filtration and cropping are dominant factors operating within the stone. These effects may also apply to stage III larvae since the flume studies suggested that these larvae do not display much improvement in swimming ability either.

Larval seaboard goby and silversides did not appear to show the increase in percent reduction over time displayed by other species. No explanation is apparent for these differences, but the data suggest that the behavior of these species is in some way different from the others.

The distribution of fish eggs between upstream and downstream positions in the experimental dike was of interest because, being passively drifting spheres, they provided insight into whether the density reduction observed for other plankton forms was due to filtration.

Results for pelagic eggs varied somewhat between 1980 and 1981 (Figure 16). In 1980, the percent difference between upstream and downstream collections was relatively small early in the season. Percent reduction

then increased later in the season as it did with some of the larvae. In 1981, a steady increase occurred through April only, and percent reduction did not appear to reach as high a level in 1981 as it did in 1980.

In spite of the variation between years, the fact that a high percentage of eggs did not pass through the stones suggests that filtration and/or cropping may be dominant factors affecting the level of entrainment at the dike. The increase in percent reduction over time may be attributed to an increase in fouling.

To examine the effect of flow path length in reducing the density of larvae, a comparison was made between the percent reduction observed through 2.4 m of rock and 1.2 m of rock. Percent reduction through 2.4 m of rock were based on upstream (A) and downstream (C) densities. Percent reduction through 1.2 m of rock were based on upstream (A) and gabion slot (B) densities. The analysis was conducted for the 7.5 cm stone section. Among the larvae, including total larvae, no significant differences were found ($p \leq 0.05$) in the percent reduction after passing through either 1.2 m or 2.4 m rock (Table 13). This was based on Wilcoxon paired-sample tests within each category. Statistical tests were not possible for cunner and sand lance due to an insufficient number of paired comparisons; however, the data appear to be similar between positions. In simple terms, these data suggest that larval densities declined across the first 1.2 m of rock and that little additional decline in numbers occurred through the second 1.2 m.

For the pelagic eggs, a significant difference ($p \leq 0.05$) due to flow path length was detected with the 1980 data set, but not within the 1981 or combined data sets.

The 7.5 and 20 cm data sets were compared for each species and species category to determine if a difference could be detected in percent reduction. No tests were made for cunner and sand lance because they lacked a sufficient

TABLE 13. PERCENT DIFFERENCE BETWEEN MEAN UPSTREAM, DOWNSTREAM AND GABION SLOT LARVAL FISH DENSITY

Date	A-C	A-B
Anchoa spp.		
1980		
June 27	64.1	61.1
July 1,2	-9.6	46.5
9,10	75.7	84.0
15,16	74.7	82.5
23,25	90.8	90.1
29,30	81.4	84.2
1981		
June 10,11	-101.8	-128.7
17,18	-9.2	5.2
23	27.8	73.3
July 9	69.1	84.2
15	34.2	79.6
Menidia spp.		
1980		
June 27	73.1	81.7
July 1,2	38.9	70.6
9,10	90.1	95.7
1981		
May 20	76.3	78.2
25	100.0	81.8
June 3,4	61.6	88.8
10,11	97.8	94.1
17,18	94.8	95.8
23	99.1	92.4
July 9	91.0	88.1
Tautoga onitis		
1980		
June 27	72.3	44.7
July 1,2	49.3	67.6
9,10	91.6	93.1
15,16	96.7	95.4
23,25	95.6	96.7
29,30	100.0	88.0
Tautogolabrus adspersus		
1980		
June 27	-10.0	68.3
July 1,2	11.3	40.8
9,10	87.0	87.2

Date	A-C	A-B
Ammodytes sp.		
1981		
March 24	-59.9	63.3
Mar 31-Apr 1	84.8	64.7
April 8	88.8	35.8
Gobiosoma ginsburgi		
1980		
June 27	81.2	78.9
July 1,2	64.7	56.9
9,10	74.9	66.5
15,16	97.3	95.1
23,25	85.7	96.3
29,30	94.3	97.5
August 7	85.0	71.7
13	79.9	73.5
21	66.8	100.0
1981		
June 3,4	63.5	86.4
10,11	59.0	65.9
17,18	81.3	-1183.9
23	62.2	92.5
July 9	-57.7	4.0
15	-25.3	23.3
Pseudopleuronectes americanus		
1981		
March 24	13.5	24.0
Mar 31-Apr 1	68.4	63.4
April 8	46.9	46.9
15	83.8	88.8
21	71.0	100.0
Total Larvae		
1980		
May 14	23.8	90.0
June 27	64.3	61.2
July 1,2	-6.6	47.4
9,10	78.1	85.2
15,16	78.7	84.9
23,25	91.0	90.5
29,30	92.8	92.5
August 7	89.2	79.0
13	83.2	84.6

(continued).

Table 13. (continued).

Date	A-C	A-B
1981		
March 24	3.0	27.9
Mar 31-Apr 1	75.3	68.4
April 8	67.9	38.2
15	83.9	80.0
21	75.0	93.4
May 6	83.1	-15.5
20	77.1	13.9
25	100.0	-36.1
June 3,4	61.9	87.9
10,11	88.4	84.9
17,18	77.0	-368.2
23	85.0	88.6
July 9	63.9	76.8
15	29.0	74.8
Pelagic Eggs		
1980		
May 8	35.4	-123.2
14	38.5	-8.0
June 27	59.7	36.0
July 1,2	71.8	45.5
9,10	91.2	87.1
15,16	94.4	90.5
23,25	87.6	90.9

Date	A-C	A-B
1981		
March 24	-253.1	-303.1
Mar 31-Apr 1	38.4	29.2
April 8	49.2	65.0
15	39.9	60.4
21	77.2	46.2
May 6	78.4	24.9
20	-64.7	-159.2
25	-9.0	42.6
June 3,4	52.3	86.5
10,11	64.6	79.7
17,18	34.7	74.6
23	-71.4	64.6
July 9	48.7	-99.0
15	71.9	12.0
Sagitta spp.		
1981		
March 24	1.7	-10.8
April 1	55.2	15.6
8	69.5	62.6
15	71.0	66.5
21	29.8	1.2
May 6	60.1	37.7
20	69.0	79.0

number of comparisons. Based on Mann-Whitney U-tests (Zar 1974), no difference in percent reduction could be detected between 7.5 and 20 cm stone channels for larval anchovy, silversides, tautog, seaboard goby and winter flounder. In other words, the 7.5 and 20 cm stone displayed comparable results in reducing the numbers of larvae of these species entrained by the dike. Among pelagic eggs and total larvae, a significant difference ($p < 0.05$) was detected. In both cases, percent reduction was greater across the 20 cm stone channel.

Adult and Juvenile Fish

Results from adult and juvenile fish impoundment and seining tests were analyzed for recovery rates. Recovery rates from the impoundment net would indicate the amount of entrainment and escape. The higher the recovery, the lower the entrainment or escape. Recovery rates from the seining would indicate the amount entrained; the higher the recovery, the higher the entrainment.

Results from the fish studies are summarized in Table 14. Data collected on October 5, 1979, September 23 and October 7, 1980, as well as March 31 and June 4, 1981, were not included in calculating the mean recovery rates because of the serious problems which developed during the impoundment periods initiated on those particular dates.

Recovery rates were highest for the Atlantic silversides (Menidia menidia), ranging from 35.0 to 100% on the 7.5 cm (3-in) side and 27.8 to 100% on the 20 cm (8-in) side, excluding data from the dates mentioned above. This appears to be consistent with data collected during the flume studies which indicated that silversides seem to avoid a rock structure. Recovery rates for striped killifish (Fundulus majalis) ranked second overall, ranging from 55.6 to 69.2% on the 7.5 cm side and 0 to 91.7% on the 20 cm side. Winter flounder (Pseudopleuronectes americanus) displayed

TABLE 14. RESULTS OF FISH IMPOUNDMENT/SEINING STUDY

Date Set	Species	Channel	No. of Fish	Total Length (cm)	Hours Set	Impoundment Recovery Number	Impoundment Recovery Percent	Seining Recovery Number	Seining Recovery Percent
1979									
9/12	M. menidia	7.5 cm	75	10-12	114	42	56.0		
		20 cm	75	10-12	114	40	53.3		
9/21	M. menidia	7.5 cm	50	10-12	74	48	96.0		
		20 cm	50	10-12	74	41	82.0		
9/28	M. menidia	7.5 cm	71	10-12	68	35	49.3		
		20 cm	71	10-12	68	69	97.2		
10/5	M. menidia	7.5 cm	40	10-12	115	0	0		
	F. majalis		29	9-12		0	0		
	M. menidia	20 cm	30	10-12	115	0	0		
	F. majalis		29	9-12		0	0		
10/15	M. menidia	7.5 cm	15	10-12	96	7	46.7		
	F. majalis		9	9-12		5	55.6		
	M. menidia	20 cm	18	10-12	96	5	27.8		
	F. majalis		13	9-12		1	7.7		
10/19	M. menidia	7.5 cm	29	10-12	72	25	86.2		
	F. majalis		31	10-12		19	61.3		
	M. menidia	20 cm	30	10-12	75	26	86.7		
	F. majalis		31	10-12		9	29.0		
11/2	M. menidia	7.5 cm	32	10-12	75	29	90.6		
	F. heteroclitus		10	10-12		1	10.0		
	F. majalis		13	10-12		9	69.2		
	M. menidia	20 cm	32	10-12	75	11	34.4		
	F. heteroclitus		10	10-12		2	20.0		
	F. majalis		12	10-12		11	91.7		

Seining Not Conducted

(continued).

TABLE 14 (continued).

Date Set	Species	Channel	No. of Fish	Total Length (cm)	Hours Set	Impoundment Recovery Number	Impoundment Recovery Percent	Seining Recovery Number	Seining Recovery Percent
11/13	T. onitis	20 cm	3	10-15	47	0	0		
	T. adspersus		13	10-15		0	0		
12/11	T. adspersus	20 cm	61	8-20	72	11	18.0		
1980									
1/28	G. aculeatus	7.5 cm	6	4-6	72	3	50.0		
	P. americanus		23	7-18		11	47.8		
	G. ginsburgi		0	3-4		4	--		
	T. adspersus	20 cm	12	10-22	72	0	0		
2/25	P. americanus	7.5 cm	21	10-22	70	3	14.3		
		20 cm	22	10-22	70	8	36.4		
3/5	P. americanus	7.5 cm	57	6-18	54	6	10.5		
		20 cm	57	6-18	54	23	40.4		
3/26	P. americanus	7.5 cm	49	10-20	44	13	26.5		
4/8	P. americanus	7.5 cm	82	6-26	54	21	25.6		
	T. onitis		0	11-18		2	--		
	T. adspersus		0	8		1	--		
7/15	F. heteroclitus	20 cm	27	8-10	24	5	18.5		
	M. menidia		8	10-12		7	87.5		
	A. rostrata		0	20-40		25	--		
	T. adspersus		0	13		1	--		
7/22	F. heteroclitus	20 cm	35	8-10	43	18	51.4		
	A. rostrata		0	20-40		25	--		
8/5	F. heteroclitus	7.5 cm	38	8-10	24	22	57.9		
	M. menidia		3	10-12		2	66.7		
	A. rostrata		0	--		9	--		
8/12	F. heteroclitus	7.5 cm	14	8-10	45.5	5	35.7		
	M. menidia		7	10-12		6	85.7		

Seining Not Conducted

(continued).

Table 14 (continued).

Date Set	Species	Channel	No. of Fish	Total Length (cm)	Hours Set	Impoundment Recovery Number	Impoundment Recovery Percent	Seining Recovery Number	Seining Recovery Percent
8/26	F. heteroclitus	20 cm	13	4-8	42	0	0		
	F. majalis		29	6-10		0	0		
	T. onitis		4	9-10		2	50.0		
	T. adspersus		3	15,8,8		3	100		
	A. rostrata		0	--		10	--		
9/9	F. heteroclitus	20 cm	4	6-10	45	0	0	0	0
	F. majalis		100	6-10		18	18.0	0	0
	M. menidia		12	7-12		12	100	0	0
9/17	F. majalis	20 cm	13	6-10	21	6	46.2	0	0
	M. menidia		190	7-12		129	67.9	0	0
	A. rostrata		0	27,40		2	--	0	0
	F. heteroclitus		0	4		2	--	0	0
	T. onitis		0	7,7		2	--	0	0
9/23	F. heteroclitus	7.5 cm	13	6-10	42	0	0	0	0
	F. majalis		20	6-10		0	0	0	0
	M. menidia		70	6-10		5	7.1	0	0
	T. onitis		16	8-17		1	6.3	0	0
10/7	F. heteroclitus	20 cm	24	6-10	41	0	0	0	0
	F. majalis		9	6-10		0	0	0	0
	M. menidia		47	6-10		3	6.4	1	2
11/12	M. menidia	20 cm	50	6-10	21	42	84.0	0	0
	F. majalis		0	7		1	--	0	0
	S. fuscus		0	18*		1	--	0	0
	T. onitis		0	11		1	--	0	0
11/18	M. menidia	20 cm	75	5-10	22	48	64.0	0	0
	F. heteroclitus		0	6-10		4	--	0	0
	S. fuscus		0	18*		1	--	0	0
12/8	M. menidia	7.5 cm	92	5-11	22	87	94.6	0	0

*Estimated length

(continued).

Table 14 (continued).

Date Set	Species	Channel	No. of Fish	Total Length (cm)	Hours Set	Impoundment Recovery Number	Impoundment Recovery Percent	Seining Recovery Number	Seining Recovery Percent
1981									
3/31	F. majalis	7.5 cm	95	6-18	42	0	0	0	0
	P. virens		0	6		1	--	0	0
	F. heteroclitus		0	4,5		1	--	0	0
	M. menidia		0	12		1	--	0	0
4/6	F. heteroclitus	7.5 cm	45	6-13	21	2	4.4	0	0
	P. virens		0	3		1	--	0	0
	M. menidia		0	9		1	--	0	0
	T. onitis		0	3		3	--	0	0
4/15	F. heteroclitus	20 cm	89	7-10	24	13	14.6	0	
	M. menidia		12	7-11		12	100	0	0
	T. onitis		0	7-28		6	--	0	0
	T. adspersus		0	9		1	--	0	
4/23	F. heteroclitus	20 cm	50	4-6	20	13	26.0	0	0
5/7	M. menidia	7.5 cm	100	8-11	19	100	100	0	0
	T. onitis		0	9-11		6	--	0	0
	T. adspersus		0	7		1	--	0	0
5/20	F. heteroclitus	20 cm	35	6-10	21	22	62.9		
	M. menidia		11	8-11		8	72.7	0	
	A. rostrata		0	25		1	--	0	
	T. onitis		0	6-11		10	--	0	
	T. adspersus		0	7		1	--		0
5/28	M. menidia	7.5 cm	65	9-12	22	49	75.4	0	
	M. tomcod		0	7		1	--	0	
	M. menidia		0	6		1	--		0
	T. onitis		0	8		2	--	0	

(continued).

Table 14 (continued).

Date Set	Species	Channel	No. of Fish	Total Length (cm)	Hours Set	Impoundment Recovery Number	Impoundment Recovery Percent	Seining Recovery Number	Seining Recovery Percent
6/4	F. heteroclitus	20 cm	4	6-10	24	0	0	0	0
	F. majalis		65	6-10		0	0	0	0
	M. menidia		31	8-11		4	12.9	0	0
	T. onitis		0	9-14		6	--	0	0
	T. adspersus		0	7		1	--	0	0
	T. maculatus		0	10,13		2	--	0	0
6/18	F. majalis	20 cm	60	7-12	24	1	1.7	0	0
	M. menidia		0	9-12		6	--	0	0
7/16	F. heteroclitus	7.5 cm	10	7-8	20	4	40.0	0	0
	M. menidia		60	6-11		21	35.0	0	0
	A. rostrata		0	25-50		8	--	0	0
7/28	F. heteroclitus	20 cm	23	6-8	22	0	0	0	0
	M. menidia		47	6-12		23	48.9	0	0
	A. rostrata		0	30		2	--	0	0
	A. aestivalis		0	4		1	--	0	0

the third highest mean recovery rate; ranges were 10.5 to 47.8% on the 7.5 cm side and 36.4 to 40.4% on the 20 cm side. Mummichog (F. heteroclitus) recovery rates ranged from 4.4 to 57.9% on the 7.5 cm side and 0 to 62.9% on the 20 cm side. Finally, cunner (Tautogolabrus adspersus), tested only on the 20 cm side, displayed recovery rates ranging from 0 to 100%. The relatively low recovery rates for mummichog, cunner and winter flounder also appeared consistent with the flume data which indicated that these species were attracted to the rocks to some extent.

Clearly, there was a great deal of variation in the recovery rates for many of the species tested. This may be attributable to natural differences in behavior of individual fish, temperature-related and seasonal variations in behavior and in technical problems with the impoundment nets. The nets were particularly susceptible to wind speed and direction which caused tearing during setting and retrieval, as well as during the impoundment period. In some cases, it was possible that fish escaped over the head ropes during high tides and heavy weather.

It is interesting to note that for both striped killifish and mummichogs, the mean recovery rate was higher for the 7.5 cm channel. This would be expected if these fish were indeed entering the gabions since the pores were considerably larger in the 20 cm channel. Mean recovery rates were about equal for both channels among Atlantic silversides. If this species did not enter the gabions as suggested by the relatively high recovery rate and flume studies, then unrecovered fish must have escaped from the enclosures. Since the nets were basically identical, the escape rate, or conversely the recovery rate, might be expected to be about equal as observed.

In many cases, when the impoundment nets were hauled, fish were found in the enclosures which were not stocked there at the beginning of the tests.

These data suggest that some fish, particularly the American eel (Anguilla rostrata), cunner and tautog (Tautoga onitis) freely moved in and out of and perhaps resides in the face of the gabions and were collected when the nets were hauled.

Channel seining began on a regular basis immediately following haul-out of the impoundment nets in September 1980. A total of 38 hauls were made following the impoundment tests conducted from September 1980 through July 1981.

Through the entire impoundment seining study, only one impounded fish was found downstream of the porous dike. This one fish, an Atlantic silverside, was believed to have fallen into the downstream chamber during retrieval of the impoundment net.

Small numbers of fish (American eel, Atlantic silverside, mummichog and tautog) were collected in the seining. These may have entered the downstream chamber through the discharge channel.

SECTION 8

REFERENCES

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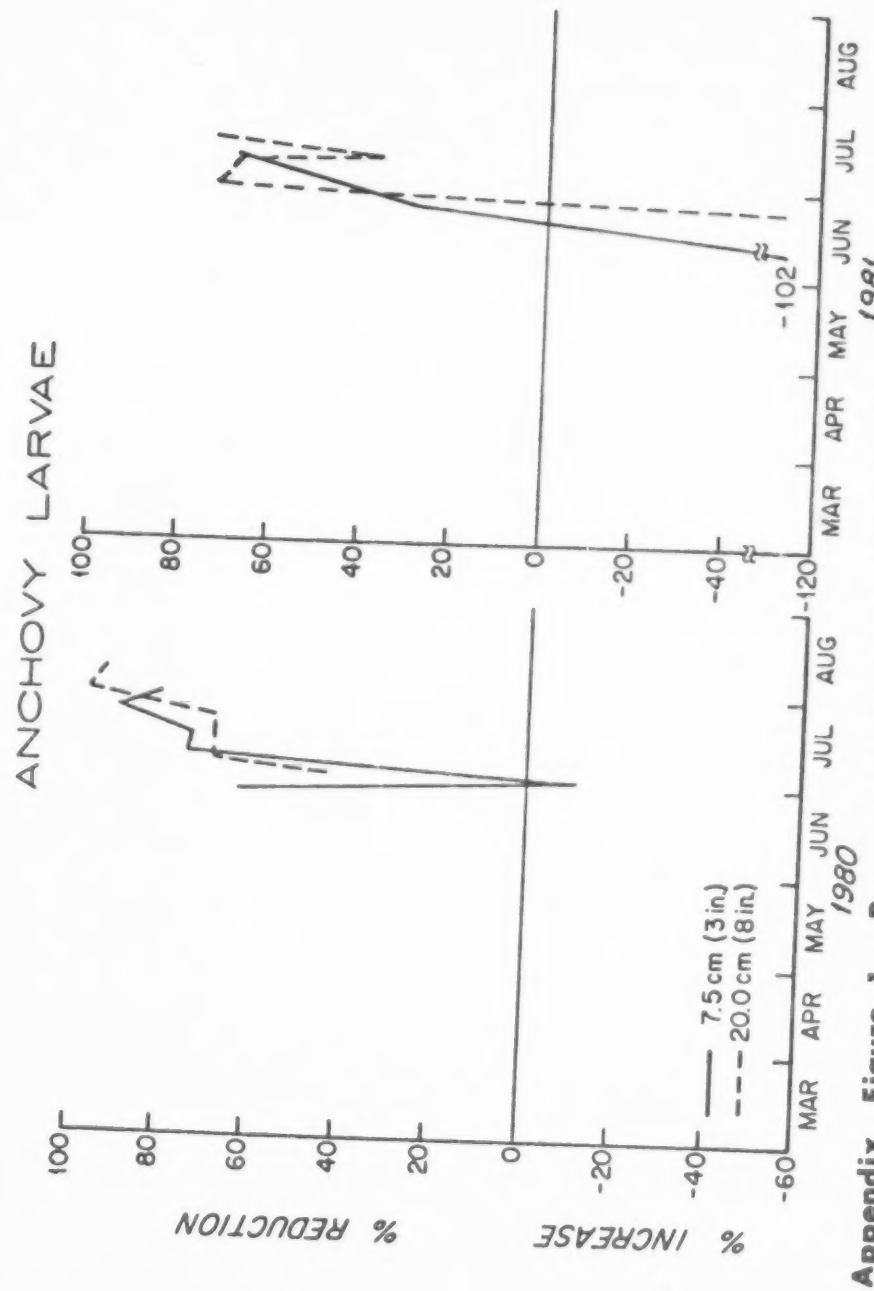
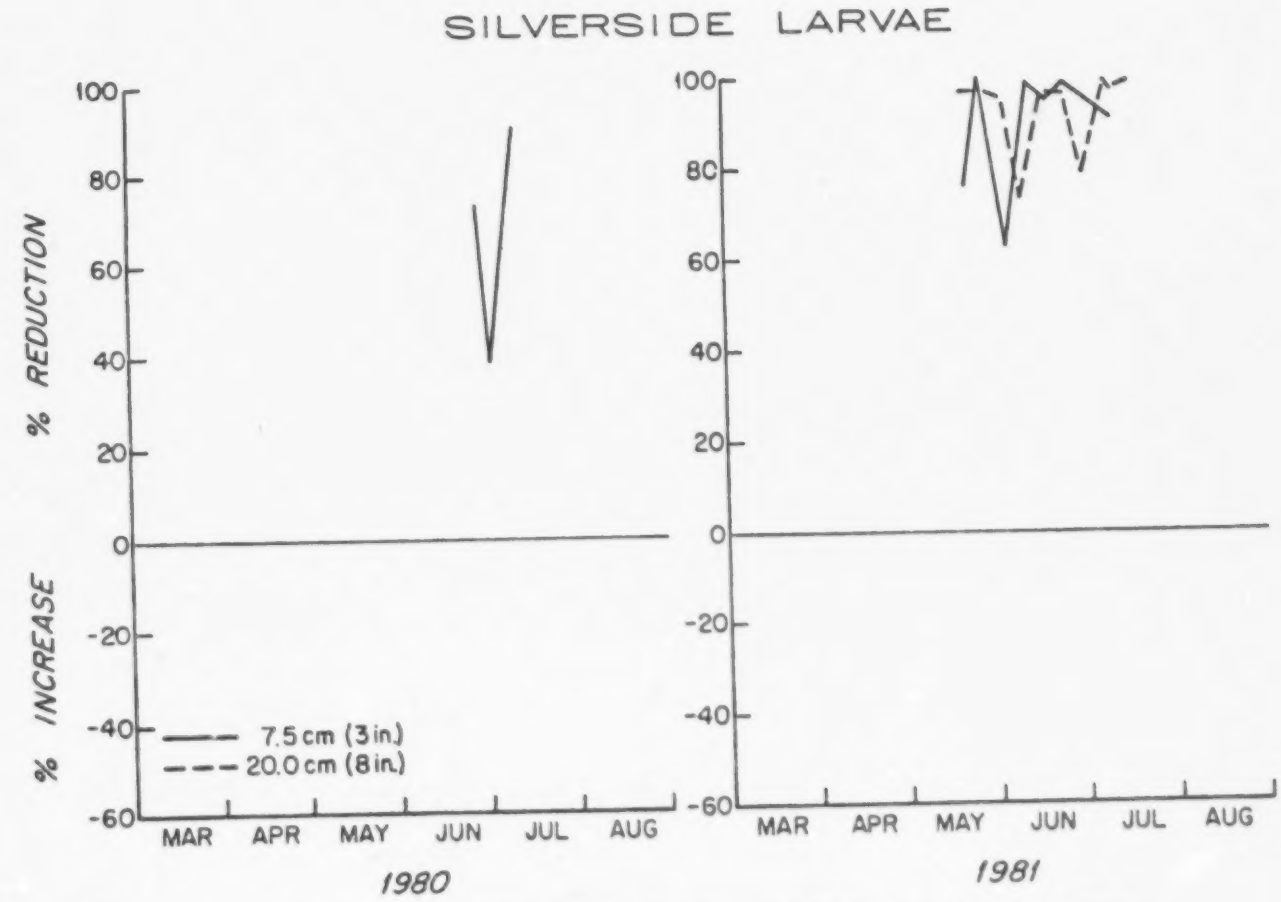
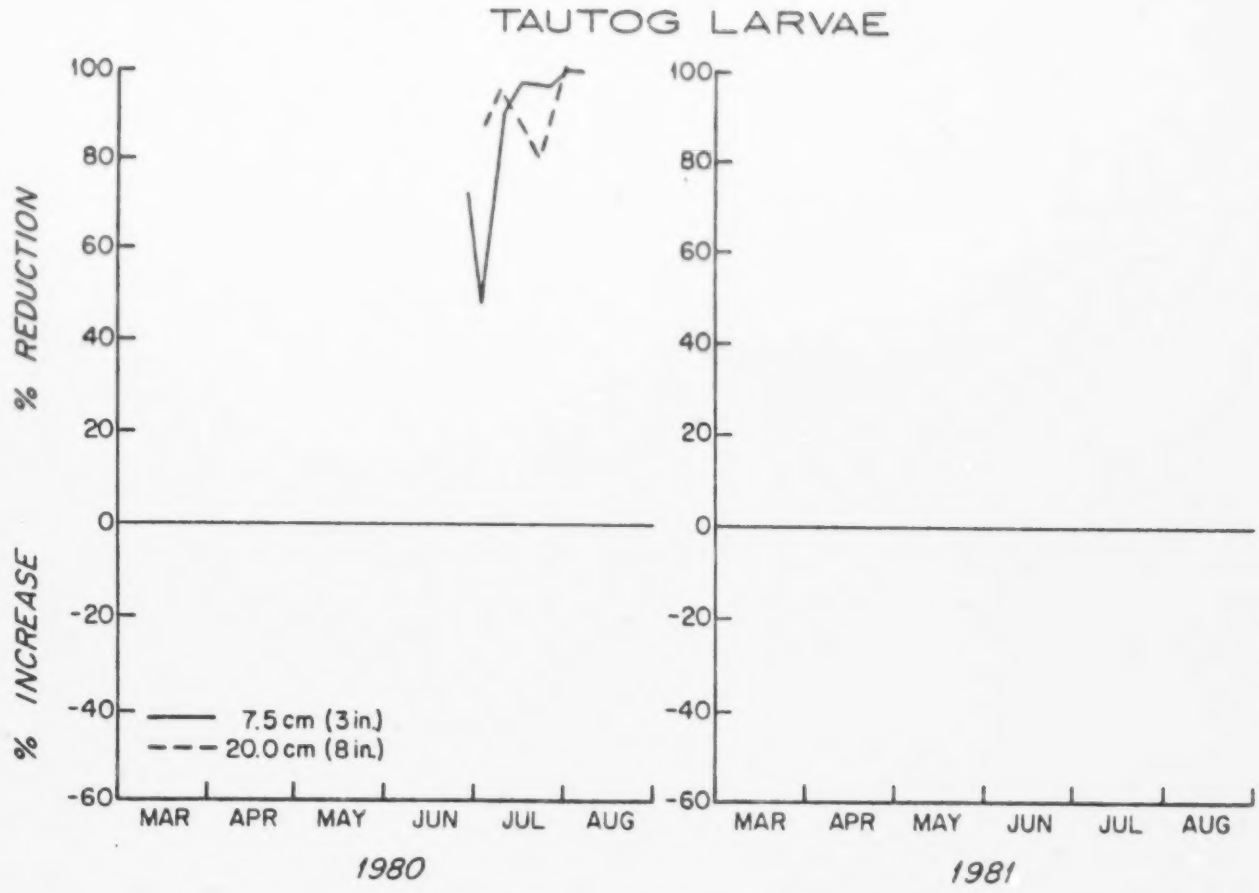
Zar, J.H. 1974. Biostatistical Analysis. Prentice-Hall, Inc., Englewood Cliffs, N.J. 630.



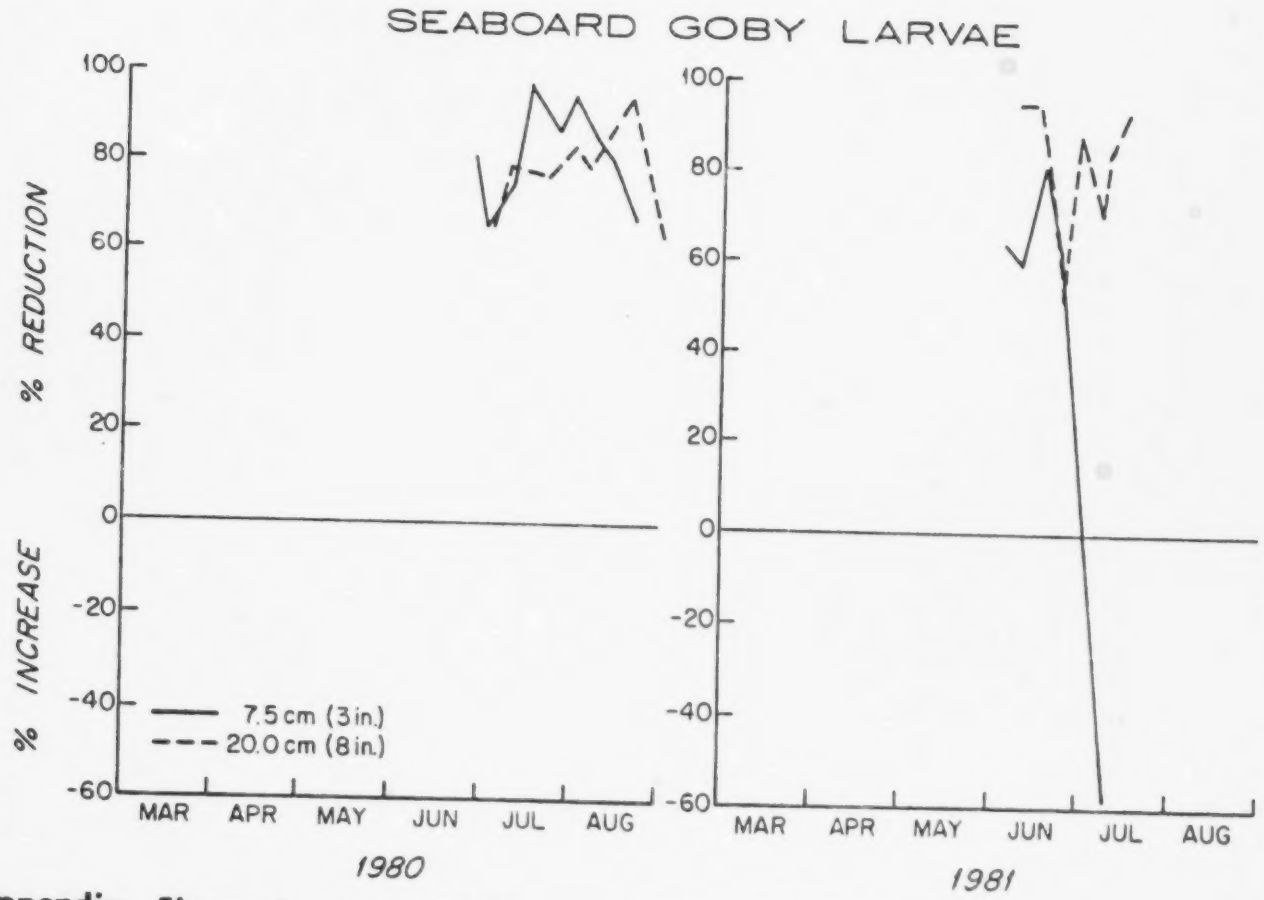
Appendix Figure 1. Percent difference in larval fish density between stations A and C.



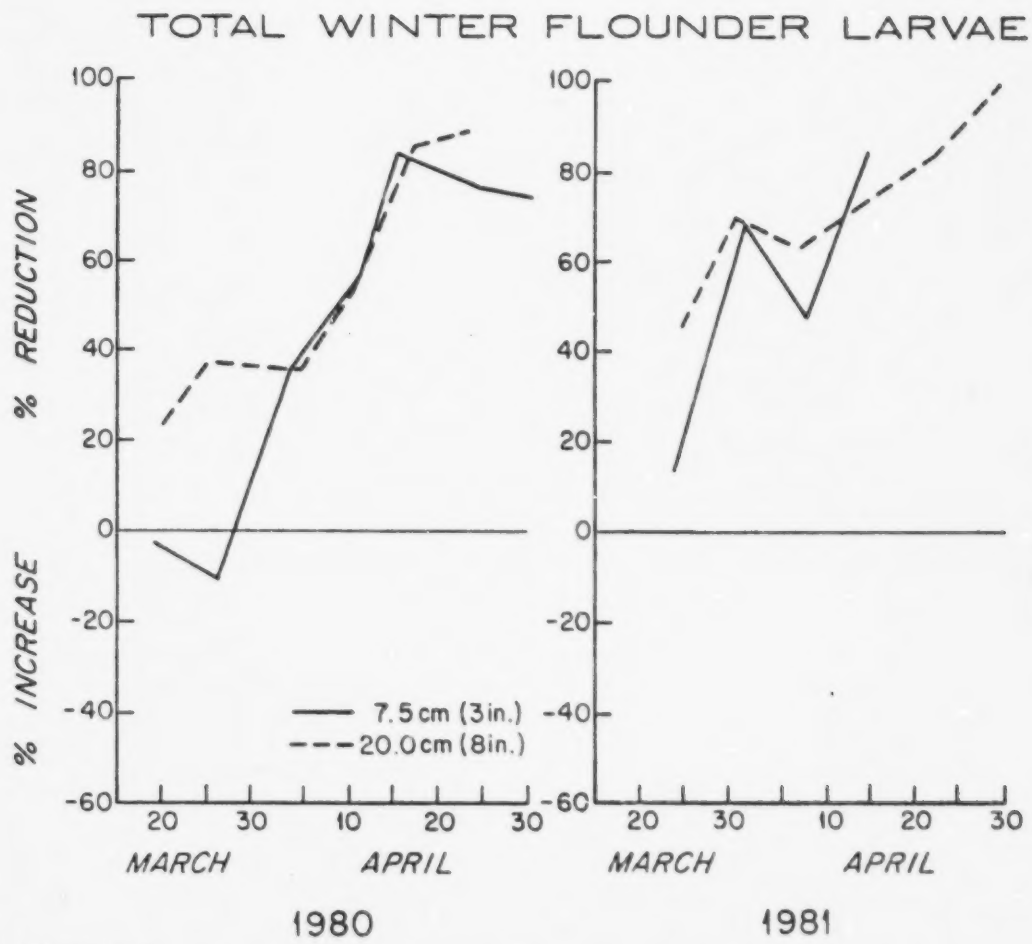
Appendix Figure 2. Percent difference in larval fish density between stations A and C.



Appendix Figure 3. Percent difference in larval fish density between stations A and C.



Appendix Figure 4. Percent difference in larval fish density between stations A and C.



Appendix Figure 5. **Percent difference in larval fish density between stations A and C.**

APPENDIX TABLE 1. MONTHLY HEAD LOSS(h) AND FLOW VOLUME(Q)

Date	Tidal Height (ft.)	8 in. Stones Q (cfs)	8 in. Stones h (ft.)	3 in. Stones Q (cfs)	3 in. Stones h (ft.)
8/31/79	12.0	7.02	1.0	5.74	1.0
12/6/80	12.4	4.93	1.8	5.62	1.8
1/8/80	12.0	5.21	1.5	4.33	1.5
	9.0	2.54	1.5	2.51	1.5
	8.0	2.12	1.5	2.25	1.5
2/12/80	9.0	3.00	1.3	4.69	1.2
	9.2	3.15	1.3	5.46	1.1
	9.3	2.89	1.6	4.62	1.5
	9.4	3.11	1.8	5.05	1.8
	9.6	3.11	1.6	5.62	1.4
	10.3	4.01	1.7	5.32	1.5
	11.4	4.95	1.6	5.99	1.5
	12.0	5.70	1.4	5.86	1.2
3/6/80	10.9	3.52	2.1	2.61	2.0
	11.1	3.71	1.9	2.75	1.9
	10.2	2.40	1.8	1.81	1.8
	8.7	1.88	1.8	1.94	1.8
	8.5	1.76	1.9	1.84	1.9
	9.0	1.72	1.7	1.47	1.7
	8.0	1.69	1.7	1.44	1.7
	9.2	2.21	1.9	2.14	1.9
	10.2	2.48	2.0	2.51	1.9
	10.5	2.66	2.0	2.38	2.0
3/17/80	7.3	2.10	1.1	1.68	1.1
	7.3	2.21	1.2	1.64	1.2
	7.9	2.55	1.4	1.91	1.4
	8.3	2.58	1.5	2.08	1.4
	9.1	3.15	1.5	2.34	1.4
	10.8	4.42	1.5	3.08	1.5
	12.4	6.56	1.6	4.12	1.5
	14.0	8.55	1.2	4.85	1.2
4/10/80	9.8	2.02	2.4	1.98	2.3
	10.5	1.69	2.4	2.01	2.4
	11.5	2.59	2.5	2.68	2.4
	12.5	4.54	2.3	3.78	2.3
	12.6	5.06	2.2	3.72	2.2
	12.0	4.54	2.2	3.25	2.2
	11.4	3.56	2.5	2.55	2.5
	10.0	2.62	2.5	2.14	2.5
	9.5	2.32	--	1.94	--
	9.0	2.40	--	1.94	--

(continued).

APPENDIX TABLE 1 (continued)

Date	Tidal Height (ft.)	8 in. Stones Q (cfs)	8 in. Stones h (ft.)	3 in. Stones Q (cfs)	3 in. Stones h (ft.)
4/28/80	10.0	2.33	2.3	2.14	2.2
	8.8	2.06	2.4	2.08	2.3
	9.0	1.99	2.3	1.91	2.2
	8.8	1.97	2.4	1.78	2.3
	9.1	2.21	2.4	1.94	2.3
	10.0	2.25	2.2	1.88	2.2
	10.5	1.90	2.5	2.11	2.4
	11.0	2.36	2.5	2.38	2.4
	12.6	3.56	2.3	2.81	2.3
6/26/80	11.0	4.80	1.5	4.56	1.6
	10.0	4.24	1.6	3.65	1.6
	8.9	3.49	1.5	3.25	1.5
	8.7	3.56	1.5	2.58	1.4
	8.4	3.41	1.5	3.12	1.4
	9.0	3.00	1.6	3.28	1.6
	9.6	3.30	1.6	3.52	1.6
	10.4	3.68	1.6	3.72	1.6
	11.2	3.90	1.7	4.12	1.6
	11.9	3.94	1.7	4.15	1.6
	12.4	4.05	1.7	4.76	1.6
7/10/80	10.4	1.65	1.9	1.68	1.9
	9.2	1.50	1.7	13.0	1.6
	8.3	1.20	1.5	1.34	1.5
	8.0	1.08	1.5	1.31	1.5
	8.7	1.31	1.7	1.71	1.7
	9.5	1.46	1.9	1.91	1.8
	10.0	1.46	2.0	1.70	2.0
	10.8	1.69	2.1	1.64	1.9
	12.0	1.91	2.3	2.21	2.2
	13.0	2.78	2.0	2.98	2.0
	13.6	3.62	1.9	3.75	1.8
7/31/80	11.0	1.28	2.5	1.94	2.4
	12.4	1.88	2.5	2.33	2.4
	13.3	3.38	2.1	3.45	1.9
	13.2	3.19	2.1	3.32	2.0
	12.1	2.44	2.2	2.68	2.1
	11.0	1.76	2.4	2.24	2.3
	9.4	1.69	2.1	1.84	2.1
	8.3	1.24	2.1	1.64	2.0
	7.8	1.20	2.1	1.70	2.0
	8.5	1.39	2.2	2.08	2.1

(continued).

APPENDIX TABLE 1 (continued)

Date	Tidal Height (ft.)	8 in. Stones Q (cfs)	8 in. Stones h (ft.)	3 in. Stones Q (cfs)	3 in. Stones h (ft.)
9/25/80	14.3	6.75	1.6	4.62	1.6
	13.2	6.75	--	4.42	--
	12.6	4.95	1.8	3.42	1.8
	10.1	3.04	1.9	2.41	1.9
	8.0	2.55	1.8	2.14	1.7
	7.5	2.36	1.8	2.08	1.8
	8.5	2.81	2.0	2.24	2.0
11/26/80	11.8	2.3	2.3	1.8	2.3
	11.5	2.2	2.4	1.8	2.3
	10.5	1.8	2.3	1.9	2.2
	9.0	1.5	2.4	1.3	2.3
	8.7	1.4	2.5	1.1	2.5
	8.8	1.4	2.7	1.5	2.6
12/18/80	8.5	1.01	2.0	1.37	2.0
	8.3	1.20	2.1	1.30	2.0
	8.5	1.0	2.2	1.31	2.1
	9.5	1.2	2.4	1.34	2.4
	11.0	1.56	2.3	1.95	2.3
	12.0	2.21	2.5	1.96	2.5
	12.0	2.40	2.2	2.44	2.2
1/22/81	7.7	1.24	2.0	0.84	2.0
	8.3	1.24	1.7	0.94	1.7
	8.5	1.11	2.0	1.08	2.0
	8.9	1.05	2.4	1.24	2.4
	9.8	1.60	2.0	1.61	2.0
	11.2	2.04	2.2	1.62	2.2
	12.3	2.93	2.3	2.01	2.3
2/26/81	9.5	2.10	1.7	2.55	1.7
	9.8	2.32	1.8	2.28	1.8
	10.0	2.66	2.0	2.38	2.0
	10.6	2.74	1.9	2.75	1.9
	11.3	3.26	2.0	2.85	2.0
	11.8	3.53	2.0	3.38	2.0
	12.0	3.90	1.7	3.42	1.7
3/11/81	8.0	2.03	1.2	1.71	1.1
	8.3	2.10	1.2	1.74	1.1
	9.5	2.18	1.5	2.34	1.4
	10.8	3.19	1.4	2.28	1.4
	11.8	4.46	1.7	3.22	1.6
	12.4	4.50	1.6	3.35	1.5
	12.7	4.88	1.6	3.89	1.5

(continued).

APPENDIX TABLE 1

Date	Tidal Height (ft.)	8 in. Stones Q (cfs)	8 in. Stones h (ft.)	3 in. Stones Q (cfs)	3 in. Stones h (ft.)
4/2/81	8.0	1.20	1.3	1.80	1.2
	8.5	1.40	1.4	1.97	1.4
	8.7	1.40	1.5	2.20	1.4
	8.9	1.42	1.6	1.66	1.6
	9.4	1.63	1.8	1.92	1.7
	11.0	2.24	1.9	2.32	2.0
	12.4	3.36	1.9	2.91	1.8
	13.0	3.72	1.8	4.35	1.8
5/11/81	9.3	2.21	1.8	1.92	1.7
	9.5	2.44	1.9	2.13	1.9
	10.0	2.92	1.9	2.21	1.8
	10.3	3.00	1.8	2.34	1.8
	11.0	2.92	1.9	2.45	1.9
	11.6	3.42	2.0	2.68	1.9
	12.0	3.56	2.0	2.72	2.0
	12.3	3.74	1.9	2.75	1.9
7/1/81	8.7	1.24	1.9	1.68	1.8
	10.0	1.35	2.1	1.64	2.0
	11.1	1.65	2.1	1.94	2.1
	12.0	1.69	2.4	2.31	2.3
	12.3	1.80	2.5	2.58	2.4
8/12/81	8.7	1.05	2.2	1.30	2.1
	9.0	1.05	2.0	1.17	2.0
	9.6	1.27	2.0	1.21	2.0
	10.0	1.35	2.3	1.61	2.2
	10.5	1.54	2.4	1.64	2.3
9/22/81	9.0	5.14	2.1	--	--
	9.5	5.02	2.4	--	--
	10.0	5.06	2.2	--	--
	10.5	5.44	2.3	--	--
	11.0	6.38	2.0	--	--
	11.5	6.94	2.0	--	--
	12.0	9.45	2.0	--	--

APPENDIX

TABLE 2. MONTHLY FLOW VOLUME(Q)

Depth (ft.)	DATE	8/79	12/80	1/80	2/80	3/80	3/80	4/80	4/80	6/
					8 in. Stones					
12		7.0	4.9	5.2	5.7	*	6.6	4.5	3.5	4.0
11					4.9	3.5	4.4	3.5	2.4	3.9
10					4.0	2.4	*	2.6	2.2	4.2
9				2.5	2.3	1.9	3.1	2.4	2.0	3.0
8				2.1	*	1.7	2.5	*	*	*
					3 in. Stones					
12		5.7	5.6	4.3	5.8	*	4.1	3.2	2.8	4.7
11					5.9	2.6	3.1	2.6	2.4	4.2
10					5.3	1.8	*	2.1	1.8	3.6
9				2.5	4.6	1.9	2.3	1.9	1.9	3.3
8				2.2	*	1.4	1.9	*	*	*

(continued).

APPENDIX TABLE 2 (continued)

Depth (ft.)	DATE	Flow Q (cfs) 7/80	7/80	9/80	10/80	12/80	1/81	2/81	3/81
				8 in. Stones					
12		1.9	2.4	4.9	2.3	2.4	2.9	3.9	4.5
11		1.7	1.8	*	2.2	1.6	2.0	3.3	3.2
10		1.5	*	3.0	1.8	1.2	1.6	2.7	*
9		1.3	1.7	2.8	1.5	1.0	1.1	2.1	2.2
8		1.1	1.2	2.6	*	1.2	1.1	*	2.0
				3 in. Stones					
12		2.2	2.7	3.4	1.8	2.4	2.0	3.4	3.4
11		1.6	2.2	*	1.8	1.9	1.6	2.9	2.3
10		1.7	*	2.4	1.9	1.3	1.6	2.4	*
9		1.7	1.8	2.2	1.3	1.3	1.2	2.5	2.3
8		1.3	1.7	2.1	*	1.3	1.0	*	1.7

(continued).

TABLE 2 (continued)

Depth (ft.)	DATE	Flow Q (cfs) 4/81	5/81	6/81	7/81	8/81	9/81
				8 in. Stones			
12		3.3	3.5	3.2	1.8	*	7.1
11		2.2	2.9	3.0	1.7	*	6.4
10		1.6	2.9	2.6	1.4	1.3	5.1
9		1.4	2.2	2.3	1.2	1.1	5.1
8		1.2	*	*	*	*	*
				3 in. Stones			
12		2.9	2.7	3.0	2.6	*	*
11		2.3	2.4	3.0	1.9	*	*
10		1.9	2.2	2.8	1.4	1.6	*
9		1.6	1.9	2.6	1.7	1.2	*
8		1.8	*	*	*	*	*

*not measured

APPENDIX TABLE 3. FOULING TUBE ANALYSIS

7.5-cm rock - December 3, 1979

Total weight: 811 grams
Weight of subsample: 111.59 grams

	Weight in Subsample	Percent	Weight in Whole Sample
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	0.81	0.73	5.89
Phylum Annelida			
Class Polychaeta			
Brania clavata) 90%			
Autolytus sp.)			
Podarke obscura			
Hydroides dianthus	1.54	1.38	11.20
Polydora ligni			
Sabellaria vulgaris			
Ampharetidae			
Eumida sanguinea			
Nereis succinea	3.92	3.51	28.51
Phylum Mollusca			
Class Gastropoda			
Tergipes tergipes	0.10	0.09	0.73
Class Gastropoda & Bivalvia			
Mya arenaria			
Crepidula plana	0.30	0.27	2.19
Mysella planulata			
Phylum Arthropoda			
Subphylum Pycnogonida			
Anaplodactylus lentus	2.53	2.27	18.42
Class Crustacea			
Order Amphipoda			
Aeginina longicornis			
Microdeutopus gryllotalpa			
Stenothoe minuta			
Melita nitida	5.02	4.50	36.52
Elasmopis levis			
Ampelisca abdita			
Subclass Cirrepedia			
Balanus sp.	15.60	13.98	113.46
Order Decapoda			
Neopanope sayi	31.41	28.15	228.48
Phylum Chordata			
Class Ascidacea			
Molgula sp.	11.90	10.66	86.52
Algae			
Mostly *Codium*	1.42	1.27	10.31
Miscellaneous			
Detritus			
Debris			
Dead hydroides			
Ostracods	37.04	33.19	269.37
Empty tubes			
Some live *Obelia* and *Tubularia*			
etc.			

(continued).

APPENDIX TABLE 3(continued).

20-cm rock - December 3, 1979 — Total weight: 712 grams; Weight of subsample: 108.45 grams

	Weight in Subsample	Percent	Weight in Whole Sample
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	1.24	1.14	8.12
Phylum Annelida			
Class Polychaeta			
Nereis succinea	1.48	1.36	9.68
Brania clavata) 90% *Autolytus* sp.) *Eumida sanguinea* *Podarke obscura* *Terebellidae* *Sabellaria vulgaris* *Polydora ligni* *Hydroides dianthus*	0.61	0.56	3.99
Phylum Mollusca			
Class Gastropoda			
Tergipes tergipes	0.15	0.14	0.99
Class Bivalvia			
Mya arenaria 90% *Mulinia lateralis* *Mytilus edulis* *Mysella planulata*	0.08	0.07	0.50
Phylum Arthropoda			
Subphylum Pycnogonida			
Anaplodactylus lentus	0.95	0.88	6.27
Class Crustacea			
Order Amphipoda			
Aeginina longicornis 95% *Microdeutopus gryllotalpa* *Stenothoe minuta* *Melita nitida* *Elasmopis levis*	6.60	6.09	43.36
Subclass Cirrepedia			
Balanus sp.	5.97	5.50	39.16
Order Decapoda			
Neopanope sayi	26.54	24.48	174.30
Phylum Chordata			
Class Ascidacea			
Molgula sp.	0.10	0.09	0.64
Algae 90% *Codium* sp.	3.34	3.08	21.92
Miscellaneous			
Detritus Debris Dead hydroides Empty tubes Some live *Obelia* and *Tubularia* etc.	61.39	56.61	403.06

(continued).

APPENDIX TABLE 3 (continued).

7.5-cm rock - March 3, 1980

Total weight: 1150 grams
Weight of subsample: 44.1 grams

	Weight in Subsample	Percent	Weight in Whole Sample
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	0.04	0.09	1.04
Phylum Annelida			
Class Polychaeta			
Brania clavata) greatest *Autolytus* sp.) amount *Podarke obscura* *Hydroides dianthus* *Polydora ligni* *Sabellaria vulgaris* Ampharetidae *Eumida sanguinea*	0.2	0.5	5.2
Nereis succinea	1.2	3.0	31.3
Phylum Mollusca			
Class Gastropoda			
Tergipes tergipes	0.1	0.2	2.6
Class Bivalvia			
Mytilus edulis (most) *Mya arenaria* *Petricola pholadiformis* *Mysella planulata*	0.3	1.0	7.8
Phylum Arthropoda			
Subphylum Pychogonida			
Anaplodactylus lentus	0.2	0.5	5.2
Class Crustacea			
Order Amphipoda			
Aeginina longicornis *Microdeutopus gryllotalpa* *Melita nitida* *Elasmopis levis* *Ampelisca abdita*	0.5	1.0	13.0
Subclass Cirrepedia			
Balanus sp.	7.2	16.0	187.8
Order Decapoda			
Neopanope sayi	4.9	11.0	127.8
Phylum Chordata			
Class Ascidacea			
Molgula sp.	9.1	21.0	237.3
Algae			
Mostly *Codium*	0.02	0.05	0.52

(continued).

APPENDIX TABLE 3 (continued).

7.5-cm rock - March 3, 1980 (continued)

	Weight in Subsample	Percent	Weight in Whole Sample
Miscellaneous detritus, debris, nematodes, ostracods, empty tubes, some live *Obelia* & *Tubularia*, dead hydroides, etc.	20.3	46.0	529.4

(continued).

APPENDIX TABLE 3 (continued).

20-cm rock - March 3, 1980

Total weight: 607 grams
Weight of subsample: 54.9 grams

	Weight in Subsample	Percent	Weight in Whole Sample
Phylum Annelida			
Class Polychaeta			
Brania clavata, *Autolytus* sp., *Podarke obscura*, *Hydroides dianthus*, *Polydora ligni*, *Sabellaria vulgaris*	0.2	0.4	2.2
Ampharetidae			
Eumida sanguinea			
Nereis succinea	0.1	0.2	1.1
Phylum Mollusca			
Class Gastropoda			
Tergipes tergipes	0.2	0.4	2.2
Class Bivalvia			
Mytilus edulis, *Mya arenaria*, *Petricola pholadiformis*	0.2	0.4	2.2
Phylum Arthropoda			
Subphylum Pychogonida			
Anaplodactylus lentus	0.3	1.0	3.3
Class Crustacea			
Order Amphipoda			
Aeginina longicornis, *Microdeutopus gryllotalpa*, *Melita nitida*, *Elasmopis levis*, *Ampelisca abdita*	0.3	1.0	3.3
Subclass Cirrepedia			
Balanus sp.	2.0	4.0	22.2
Order Decapoda			
Neopanope sayi	10.8	20.0	119.6
Phylum Chordata			
Class Ascidacea			
Molgula sp.	0.2	0.4	2.2
Algae			
Mostly *Codium*	1.9	3.0	21.0
Miscellaneous detritus, debris, dead hydroides, ostracods, nematodes, empty tubes, some live *Obelia* & *Tubularia*, etc.	38.7	70.0	427.9

(continued).

APPENDIX TABLE 3 (continued).

7.5-cm rock - June 5, 1980

Total weight = 2063
Weight of subsample = 137.68 gms

	Weight in Subsample	Percent	Weight in Whole Sample
Phylum Cnidaria			
Class Anthozoa			
Metridium sp.	0.16	0.1	2.40
Phylum Annelida			
Class Polychaeta			
Polydora ligni (75%) *Harmothoe extenuata* *H. imbricata* *Hydroides dianthus* *Sabellaria vulgaris* *Eumida sanguinea* *Brania clavata* *Podarke obscura* Terebellidae	0.87	0.6	13.04
Nereis succinea	1.87	1.4	28.02
Phylum Mollusca			
Class Gastropoda			
Crepidula fornicata	0.02	0.15	0.30
Class Bivalvia			
Mya arenaria	1.14	0.8	17.08
Mytilus edulis	45.59	33.1	683.12
Petricola pholadiformis	0.03	0.02	0.45
Phylum Arthropoda			
Subphylum Pychogonida	0.02	0.05	0.30
Class Crustacea			
Order Amphipoda			
Microdeutopus spp. (99%) *Corophium* sp. *Melita nitida* Caprellidae	0.10	0.07	1.50
Order Decapoda			
Neopanope sayi and fragments	1.08	1.0	16.18
Subclass Cirrepedia			
Balanus spp.	57.36	42.0	859.48

(continued).

APPENDIX TABLE 3 (continued).

7.5-cm rock - June 5, 1980 (continued)

	Weight in Subsample	Percent	Weight in Whole Sample
Phylum Chordata			
Class Ascidacea			
Molgula sp.	9.17	7.0	137.40
Misc. + debris + detritus	20.27	15.0	303.73
Phylum Ectoprocta			
Cryptosula sp.	present but unmeasurable		

(continued).

APPENDIX TABLE 3 (continued).

20-cm rock - June 5, 1980

Total weight = 1323 gms
Weight of subsample = 108.99 gms

	Weight in Subsample	Percent	Weight in Whole Sample
Phylum Cnidaria			
Class Anthozoa			
Metridium sp.	0.02	0.018	0.24
Phylum Annelida			
Class Polychaeta			
Polydora ligni (50%)			
Harmothoe extenuata } very			
H. imbricata } abundant			
Hydroides dianthus			
Sabella microphthalma			
Brania clavata			
Capitella capitata	1.42	1.3	17.24
Autolytus sp.			
Eumida sanguinea			
Spio filicornis			
Podarke obscura			
Terebellidae			
Nereis succinea	1.20	1.1	14.57
Phylum Mollusca			
Class Gastropoda			
Mitrella lunata	0.02	0.018	0.24
Class Bivalvia			
Crassostrea virginica	0.78	0.7	9.47
Mya arenaria	1.04	1.0	12.62
Mytilus edulis	33.57	30.8	407.50
Petricola pholadiformis	0.03	0.027	0.37
Phylum Arthropoda			
Subphylum Pycnogonida	0.01	0.009	0.12
Class Crustacea			
Order Amphipoda			
Microdeutopus spp. (99%)			
Caprellidae			
Corophium sp.	0.25	0.2	3.03
Jassa falcata			
Order Decapoda (fragments)	0.63	0.6	7.65

(continued).

APPENDIX TABLE 3 (continued).

20-cm rock - June 5, 1980 (continued)

	Weight in Subsample	Percent	Weight in Whole Sample
Subclass Cirrepedia			
Balanus spp.	27.32	25.0	331.63
Phylum Chordata			
Class Ascidacea			
Molgula sp.	0.52	0.5	6.31
Misc. + debris + detritus	42.18	38.6	512.01
Phylum Ectoprocta			
Cryptosula sp.	present but unmeasurable		

APPENDIX TABLE 3 (continued).

7.5-cm rock - September 11, 1980

Total weight = 2595 gms
Weight of subsample = 35.93

	Weight in Subsample	Percent	Weight in whole Sample
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	0.11	0.3	7.95
Phylum Annelida			
Class Polychaeta			
Nereis succinea	1.19	3.3	85.95
Hydroides dianthus	1.57	4.4	113.39
Polydora ligni, *Brania clavata*, *Autolytus* sp., *Podarke obscura*	0.04	0.1	2.89
Phylum Mollusca			
Class Gastropoda			
Crepidula fornicata, *Mitrella lunata*, *Tergipes tergipes*, *Urosalpinx cinerea*	1.30	3.6	93.89
Class Bivalvia			
Mytilus edulis	0.57	1.6	41.17
Phylum Arthropoda			
Subphylum Pycnogonida	0.04	0.1	2.89
Subphylum Mandibulata			
Class Crustacea			
Amphipoda			
Caprellidae (90%), *Jassa falcata*, *Corophium* spp., *Microdeutopus* spp., *Melita* sp.	4.02	11.2	290.34
Decapoda			
Neopanope sayi	2.89	8.0	208.73
Cirrepedia			
Balanus spp.	6.84	19.0	494.01
Phylum Chordata			
Class Ascidacea			
Molgula sp.	4.25	11.8	306.95
Miscellaneous			
detritus, debris, bryozoa - *Bowerbankia*, algae, etc.	13.11	36.5	946.85

Encrusting bryozoans such as *Cryptosula* and *Schizoporella* present but unmeasurable.

(continued).

APPENDIX TABLE 3 (continued).

20-cm rock - September 11, 1980

Total weight = 1951 gms
Weight of subsample = 15.06

	Weight in Subsample	Percent	Weight in whole Sample
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	0.08	0.5	10.36
Phylum Annelida			
Class Polychaeta			
Nereis succinea	0.28	1.9	36.27
Hydroides dianthus	0.04	0.3	5.18
Autolytus sp. *Polydora ligni* *Brania clavata* *Sabella microphthalma*	0.09	0.6	11.66
Phylum Arthropoda			
Subphylum Pycnogonida			
Anaplodactylus lentus	0.06	0.4	7.77
Subphylum Mandibulata			
Class Crustacea			
Amphipoda			
Caprellidae (90%) *Corophium* spp. *Microdeutopus* spp. *Jassa falcata* *Melita* sp.	4.49	29.8	581.67
Decapoda			
Neopanope sayi	2.46	16.3	318.69
Cirrepedia			
Balanus spp.	1.11	7.4	143.80
Phylum Chordata			
Class Ascidacea			
Molgula sp.	0.74	4.9	95.87
Miscellaneous			
detritus debris nematodes empty tubes animal fragments algae bryozoa - mostly *Bowerbankia*	5.71	37.9	739.72

Encrusting bryozoa such as *Cryptosula* and *Schizoporella* present but unmeasurable.

(continued).

APPENDIX TABLE 3 (continued).

7.5-cm rock - March 3, 1981

Total weight: 3384 grams weight of subsample: 71 grams

	Weight in Subsample	Percent	Weight in Total
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	0.13	0.2	6.20
Phylum Platyhelminthes			
Class Turbellaria	0.003	0.004	0.14
Phylum Annelida			
Class Polychaeta			
Nereis succinea	1.57	2.2	74.83
*Hydroides dianthus**			
Brania clavata			
Polydora ligni			
Sabella microphthalma	5.74	8.1	273.58
Podarke obscura			
Sabellaria vulgaris			
(*most of polychaete weight is due to calcareous tubes)			
Phylum Mollusca			
Class Gastropoda			
Crepidula plana (live & *C. fornicata* dead)	2.32	3.3	110.58
Other molluscs (live & dead)			
Mytilus edulis			
Mitrella lunata	0.14	0.2	6.67
Mya arenaria			
Phylum Arthropoda			
Subphylum Pychogonida	0.18	0.3	8.60
Subphylum Mandibulata			
Class Crustacea			
Amphipoda			
Corophium sp., *Jassa falcata*, *Melita* sp. (99%)	0.48	0.7	22.88
Decapoda			
Neopanope sayi	3.29	4.6	156.81
Cirrepedia			
Balanus spp. (most are dead)	15.18	21.4	723.51
Debris - lots of dead organic matter and nematodes	41.98	59.1	2000.85

Encrusting bryozoa abundant but unmeasurable

(continued).

APPENDIX TABLE 3 (continued).

20-cm rock - March 3, 1981

Total weight: 3176.5 gms weight of subsample: 73.2 gms

	Weight in Subsample	Percent	Weight in Total
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	0.22	0.3	9.54
Phylum Platyhelminthes			
Class Turbellaria	trace		
Phylum Annelida			
Class Polychaeta			
Nereis succinea	1.40	1.9	60.75
Polydora ligni, *Brania clavata*, *Hydroides dianthus*, *Sabella microphthalma*, Miscellaneous	1.14	1.6	49.47
Phylum Mollusca			
Class Gastropoda			
Crepidula fornicata	3.75	5.1	162.73
C. plana	1.21	1.7	52.50
Class Bivalvia			
Mytilus edulis	trace		
Phylum Arthropoda			
Subphylum Pycnogonida	0.002	0.003	0.087
Subphylum Mandibulata			
Class Crustacea			
Amphipoda			
Corophium sp., *Jassa falcata*, *Microdeutopus* sp. (99%)	0.74	1.0	32.11
Decapoda			
Neopanope sayi	5.83	8.0	252.99
Cirrepedia			
Balanus spp. (mostly dead)	10.23	14.0	443.93
Phylum Bryozoa			
Botryllus schlosseri	0.69	0.9	29.94
Algae - *Enteromorpha* sp.	trace		
Debris - lots of dead organic matter and nematodes	48.00	65.5	2082.95
Encrusting bryozoa abundant but unmeasurable			

(continued).

APPENDIX TABLE 3 (continued).

7.5-cm rock - March 10, 1981

Total weight: 3044 grams Subsample weight: 86.10

	Weight in Subsample	Percent	Weight in whole Sample
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	0.29	0.3	10.25
Phylum Platyhelminthes			
Class Turbellaria	trace		
Phylum Annelida			
Class Polychaeta			
Polydora ligni (most) *Sabella microphthalma* *Sabellaria vulgaris* *Brania clavata* Terebellidae *Lepidonotus squamatus* Lumbrinereidae *Autolytus* sp.	1.31	1.5	46.31
Nereis succinea	1.79	2.1	63.28
Hydroides dianthus (many empty calcareous tubes)	9.65	11.2	341.17
Phylum Mollusca			
Class Gastropoda			
Crepidula fornicata (live & dead)	6.15	7.1	217.43
Class Bivalvia (mostly dead shells)			
Mya arenaria *Mytilus edulis* *Modiolus modiolus*	2.33	2.7	82.38
Phylum Arthropoda			
Subphylum Pycnogonida	0.01	0.01	0.35
Subphylum Mandibulata			
Class Crustacea			
Amphipoda			
Jassa falcata *Corophium* sp. } 95% *Microdeutopus* sp. *Melita* sp.	5.00	5.8	176.77
Decapoda			
Neopanope sayi	0.85	1.0	30.05
Cirrepedia			
Balanus spp.	14.75	17.1	521.47
Phylum Bryozoa			
Botryllus schlosseri	3.12	3.6	109.60
Phylum Chordata			
Class Ascidacea			
Molgula sp.	0.82	1.0	28.99
Algae (Enteromorpha)	trace		
Debris, detritus (dead organic matter, empty tubes, etc.)	40.03	46.5	1415.23

Encrusting Bryozoa abundant but unmeasurable.

(continued).

APPENDIX TABLE 3 (continued).

20-cm rock - March 10, 1981

Total weight: 2849 grams Subsample weight: 75.22 grams

	Weight in Subsample	Percent	Weight in whole sample
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	0.08	0.1	3.03
Phylum Platyhelminthes			
Class Turbellaria	0.06	0.1	2.27
Phylum Annelida			
Class Polychaeta			
Sabella microphthalma (most abun.), *Brania clavata*, *Polydora ligni*	0.74	1.0	28.03
Nereis succinea	0.38	0.5	14.39
Hydroides dianthus (mostly empty calcareous tubes)	0.21	0.3	7.95
Phylum Mollusca			
Class Gastropoda			
Crepidula fornicata (live & dead)	2.56	3.4	96.96
C. plana (live & dead)	0.85	1.1	32.19
Class Bivalvia			
Mytilidae (juveniles)	0.08	0.1	3.03
Phylum Arthropoda			
Subphylum Pycnogonida	trace		
Subphylum Mandibulata			
Class Crustacea			
Amphipoda			
Jassa falcata, *Corophium* sp., *Melita* sp. (95%)	0.18	0.2	6.82
Decapoda			
Neopanope sayi	3.11	4.1	117.79
Cirrepedia			
Balanus spp.	9.25	12.3	350.35
Algae (Enteromorpha)	trace		
Debris (dead organic matter, empty tubes, etc.)	57.72	76.7	2186.18

Encrusting Bryozoa present but unmeasurable.

(continued).

APPENDIX TABLE 3 (continued).

7.5-cm rock - April 17, 1981

Total weight: 2455 grams Weight of subsample: 101.83 grams

	Weight in Subsample	Percent	Weight in whole Sample
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	0.14	0.14	3.38
Phylum Platyhelminthes			
Class Turbellaria	0.49	0.48	11.81
Phylum Annelida			
Class Polychaeta			
Polydora ligni (50%) *Brania clavata* Polynoidae (juveniles) *Sabella microphthalma* *Podarke obscura*	0.94	0.92	22.66
Hydroides dianthus	28.02	27.52	675.53
Nereis succinea	3.00	2.95	72.33
Phylum Mollusca			
Class Gastropoda			
Crepidula fornicata	3.74	3.67	90.17
Class Bivalvia			
Mytilus (fragments) *Crassostrea virginica* (1)	0.22	0.22	5.30
Phylum Arthropoda			
Subphylum Mandibulata			
Class Crustacea			
Amphipoda			
Jassa falcata (99%) *Corophium* sp. *Melita* sp.	6.05	5.94	145.86
Decapoda			
Neopanope sayi	12.64	12.41	304.74
Cirrepedia			
Balanus spp.	14.34	14.08	345.72
Phylum Bryozoa			
Botryllus schlosseri	1.82	1.79	43.88
Phylum Chordata			
Class Ascidacea			
Molgula sp.	0.76	0.75	18.32
Miscellaneous			
Algae (dead)	0.31	0.30	7.47
Debris, detritus, etc.	29.36	28.83	707.83

Encrusting bryozoa present but unmeasurable.

(continued).

APPENDIX TABLE 3 (continued).

20-cm rock - April 17, 1981

Total weight: 1050 grams Weight of subsample: 130.2 grams

	Weight in Subsample	Percent	Weight in whole Sample
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	0.92	0.71	7.42
Phylum Annelida			
Class Polychaeta			
Polydora ligni (90%) Polynoidae (juveniles) *Brania clavata* *Spio filicornis*	0.44	0.34	3.55
Nereis succinea	0.95	0.73	7.66
Hydroides dianthus	0.47	0.36	3.79
Phylum Mollusca			
Class Gastropoda			
Crepidula fornicata	19.88	15.27	160.32
Class Bivalvia			
Mytilus edulis	0.07	0.05	0.56
Phylum Arthropoda			
Class Crustacea			
Amphipoda			
Jassa falcata (99%) *Corophium* sp.	6.94	5.33	55.97
Cirrepedia			
Balanus spp.	43.47	33.39	350.56
Decapoda			
Neopanope sayi	6.03	4.63	48.63
Algae	0.06	0.05	0.48
Detritus, debris, misc.	50.97	39.15	411.05

Encrusting bryozoa present but unmeasurable.

(continued).

APPENDIX TABLE 3 (continued).

7.5-cm rock - June 10, 1981

Total weight: 2615 grams weight of subsample: 58.03 grams

	Weight in Subsample	Percent	Weight in Total
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	0.30	0.52	13.52
Phylum Annelida			
Class Polychaeta			
Polydora ligni, *Sabella microphthalma*, Lumbrinereidae, *Harmothoe* sp., *Autolytus* sp., *Brania clavata*	0.49	0.84	22.08
Hydroides dianthus	7.94	13.68	357.80
Nereis succinea	0.87	1.50	39.20
Phylum Mollusca			
Class Gastropoda			
Crepidula fornicata (live & dead)	3.98	6.85	179.35
Class Bivalvia			
Mytilus edulis, Misc. dead shells	2.47	4.26	111.31
Phylum Arthropoda			
Subphylum Pycnogonida	trace	-	-
Subphylum Mandibulata			
Class Crustacea			
Amphipoda			
Jassa falcata, *Corophium* sp., *Melita* sp. (90%)	1.41	2.43	63.54
Decapoda			
Neopanope sayi	1.09	1.88	49.12
Cirrepedia			
Balanus spp.	10.71	18.46	482.62
Algae	trace	-	-
Detritus, bryozoa, debris, misc.	28.77	49.58	1296.46

Encrusting bryozoa present but unmeasurable

(continuing).

APPENDIX TABLE 3 (continued).

20-cm rock - June 10, 1981

Total weight: 2488 grams weight of subsample: 55.03 grams

	Weight in Subsample	Percent	Weight in Total
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	0.96	1.74	43.40
Phylum Annelida			
Class Polychaeta			
Polydora ligni, *Brania clavata*, *Sabella microphthalma*	0.05	0.09	2.26
Hydroides dianthus	0.20	0.36	9.04
Nereis succinea	0.01	0.02	0.45
Phylum Mollusca			
Class Gastropoda			
Crepidula fornicata	11.22	20.39	507.28
C. plana	4.16	7.56	188.08
Class Bivalvia			
Mytilus edulis	0.63	1.14	28.48
Phylum Arthropoda			
Class Crustacea			
Amphipoda			
Jassa falcata (95%), *Corophium* sp., *Melita* sp.	3.41	6.20	154.17
Decapoda			
Neopanope sayi	3.67	6.67	165.93
Cirrepedia			
Balanus spp.	11.45	20.81	517.67
Algae (mostly *Enteromorpha*)	0.32	0.58	14.47
Detritus, bryozoa, debris, misc.	18.95	34.44	856.76
Encrusting bryozoa present but unmeasurable			

(continuing).

APPENDIX TABLE 3 (continued).

7.5-cm rock - July 29, 1981

Total weight: 2532 grams weight of subsample: 85.92 grams

	Weight in Subsample	Percent	Weight in Total
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	0.40	0.47	11.79
Phylum Annelida			
Class Polychaeta			
Polydora ligni (80%) *Podarke obscura* *Eumida sanguinea* *Capitella capitata* Sabellidae *Brania clavata*	0.64	0.74	18.86
Nereis succinea	1.28	1.49	37.72
Hydroides dianthus	6.86	7.98	202.16
Phylum Mollusca			
Class Gastropoda			
Crepidula plana (shells)	3.32	3.86	97.84
C. fornicata	1.17	1.36	34.48
Class Bivalvia			
Mytilus edulis (shells)	2.88	3.35	84.87
Misc. juveniles *Mulinia lateralis* *Mercenaria mercenaria* *Petricola pholadiformis*	0.02	0.02	0.59
Phylum Arthropoda			
Subphylum Pycnogonida	0.03	0.03	0.88
Subphylum Mandibulata			
Class Crustacea			
Amphipoda *Microdeutopus* sp. *Corophium* sp. *Ampelisca* sp. *Melita* sp. Photidae	0.59	0.69	17.39
Decapoda *Neopanope sayi* and decapod fragments	0.62	0.72	18.27
Cirrepedia *Balanus* spp.	23.69	27.57	698.13
Phylum Chordata			
Class Ascidacea			
Molgula sp.	5.12	5.96	150.88
Debris, detritus, misc.	39.30	45.74	1158.14

(continued).

APPENDIX TABLE 3 (continued).

20-cm rock - July 29, 1981

Total weight: 3593 grams weight of subsample: 70.38 grams

	Weight in Subsample	Percent	Weight in Total
Phylum Cnidaria			
Class Anthozoa			
Metridium senile	0.73	1.04	37.27
Phylum Platyhelminthes			
Class Turbellaria	trace		
Phylum Annelida			
Class Polychaeta			
Polydora ligni (80%) *Eumida sanguinea* *Podarke obscura* *Brania clavata* *Capitella capitata* Sabellidae	0.25	0.36	12.76
Nereis succinea	0.81	1.15	41.35
Hydroides dianthus	5.73	8.14	292.52
Phylum Mollusca			
Class Gastropoda			
Crepidula fornicata (shells)	5.94	8.44	303.25
C. plana (shells)	0.65	0.92	33.18
Mitrella lunata	trace		
Class Bivalvia			
Mytilus edulis (shells)	3.13	4.45	159.79
Misc. juveniles *Mercenaria mercenaria* *Petricola pholadiformis* *Mulinia lateralis* *Anomia simplex*	0.06	0.09	3.06
Phylum Arthropoda			
Subphylum Pycnogonida	0.11	0.16	5.62
Subphylum Mandibulata			
Class Crustacea			
Amphipoda *Microdeutopus* sp. *Ampelisca* sp. *Corophium* sp.	0.05	0.07	2.55
Decapoda *Neopanope sayi* and decapod fragments	1.07	1.52	54.63
Cirrepedia *Balanus* spp.	7.23	10.27	369.10
Phylum Chordata			
Class Ascidacea *Molgula* sp.	14.41	20.47	735.65
Algae (dead)	0.31	0.44	15.83
Debris, detritus, misc.	29.90	42.48	1526.44

Encrusting bryozoa present but unmeasurable.